BEST MANAGEMENT PRACTICES IN NONFERROUS METALS MINING AND PROCESSING

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ENVIRONMENTAL POLLUTION PREVENTION PROJECT (EP3)

September 1998

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EXECUTIVE SUMMARY

This manual provides Best Management Practices (BMPs) for the mining industry; it covers all processes of the mining industry, from the actual mining extraction to the mineral processing and metal refining operations. It is intended for the mining facilities, policy makers, and all other stockholders in the mining industry in the Andean countries.

STRUCTURE OF THE MANUAL

The manual covers three stages of operations in nonferrous metals mining and processing: mining (extraction), ore processing (mineral processing), smelting and metal refining. Chapters 2 and 3 describe the basic methods of mining and ore processing, respectively, typical wastes from each operation, and best management practices (BMPs) for minimizing their environmental impacts.

Chapter 4 discusses major categories of environmental impacts from a mining site as a whole both during and after completion of operations. It presents BMPs and mitigation and rehabilitation measures for each category of impacts. Chapter 5 considers waste streams and environmental improvement options in equipment maintenance and housekeeping at the mining site.

Chapter 6 focuses on mineral processing and refining of nonferrous metals from ore concentrates. It describes typical wastes and BMPs both in general for this category of operations and specifically for processing of individual metals.

Chapter 7 deals with environmental management procedures that help mining companies improve their environmental performance. The chapter introduces the concept of the ISO 14000 standard and describes the main components of an environmental management system (EMS).

CHAPTER 1
INTRODUCTION

Recent political and economic reforms have led to dramatic increases in private investment in metals exploration and mining in South American countries, especially in Chile, Peru, and Bolivia. It is estimated that about $900 million was spent in Latin America on exploration alone in 1996, and this figure does not include capital investments. Many U.S., Canadian, Australian, and European mining companies are looking to South America for opportunities to expand their operations and to transfer advanced mining technologies.

Metals mining and processing can be a source of considerable environmental damage to natural resources. Potential contamination of surface and ground waters, solid waste management problems, dust emissions, land disturbance, and habitat destruction are the main types of environmental impacts of mining-related activities. The deterioration of public health and natural resources can have a negative impact on a country=s long-term growth potential, even if immediate economic benefits may be gained by individual mining companies. As free trade expands in the Americas, it is becoming increasingly important that progressive environmental management be integrated into the region=s mining operations.

1.1 OBJECTIVE OF THE MANUAL

The objective of this manual is to describe the best technologies and environmental management practices in the mining and mineral processing industry that offer the greatest opportunity for environmental protection and cost savings through pollution prevention and control. The manual also alerts foreign investors in South America=s mining industry to what needs to be done to encourage environmentally sustainable development in the years to come. The manual focuses on mining of nonferrous metals that are commercially important in South America: copper, lead, zinc, gold, silver, tin, and aluminum.

It is intended that mining industry representatives (both technical and operations) will use the described procedures and technologies to minimize potential environmental impacts and increase efficiency of operations. The manual will also be useful for government officials involved in

environmental and mining industry regulation, since it outlines technical, planning, and management tools that foster improved environmental performance.

1.2 METALS MINING INDUSTRY IN SOUTH AMERICA: TRENDS AND PRIORITIES

Today, commercial metals mining activities are found in practically all South American countries. In Bolivia, Chile, and Peru, mining provides over 25% of export revenues. Over the past decade, the economies of many countries of the region have been liberalized, parastatal companies have been privatized, and foreign investors have been encouraged to invest in the mining industry. As a result, South America now ranks first in the world in terms of mining exploration expenditures. Chile, which started reforms a decade ahead of the others, has taken the lead, attracting several billion dollars in private investments. Argentina, Bolivia, Ecuador, and Peru are in the advanced stages of transformation toward a privatized mining industry.

The mining industry in South America varies from one country to the next in terms of the minerals produced, the size of operations, the types of mining, and the form of ownership involved. This section provides a brief overview of the main features and trends in nonferrous metals mining in the region.

1.2.1 Key Nonferrous Metals Mined

Commercial mineral production in South American is highly diversified. The most important nonferrous metals mined include copper, lead, zinc, gold, silver, tin, and aluminum. Chile is the world=s largest copper producer, Peru ranks third in the world in the production of silver, zinc, and lead, and Brazil is among the largest bauxite (aluminum) producers in the world.

Table 1-1 presents the data on the production of principal nonferrous metals in selected South American countries.

Table 1-1
Production of Key Nonferrous Metals in South America, 1996
(thousand metric tons, unless otherwise indicated)

Country	Copper	Lead	Zinc	Gold, MT	Silver*	Tin	Aluminum
Argentina	n/a	11.3	31.1	1.2	0.05	n/a	n/a
Bolivia	0.1	16.5	145.1	12.6	0.4	14.8	n/a
Brazil	46.2	6.0	167.4	76.8	0.06	20.3	10,000.0
Chile	3,052.4	1.1	35.6	51.8	1.0	n/a	n/a
Colombia	2.4	n/a	0.1	1.7	0.01	n/a	n/a
Peru	479.4	248.6	758.4	66.1	1.9	26.7	n/a
Venezuela	n/a	n/a	n/a	3.3	n/a	n/a	5,600.0

n/a X not applicable.
Source: World Bureau of Mining Statistics
* 1995 figures from Mineral Industries of Latin America and Canada

1.2.2 Production Trends for Selected Countries

Metals mining is a major economic activity in Chile, Peru, and Bolivia, constituting between 5% and 25% of the GDP and 25-50% of industrial export revenues (World Bank, 1996). Mining is also important in Surinam and Guyana where it consists almost exclusively of bauxite production. In Brazil and Venezuela mining is significant but represents only a small percentage of the GDP (1-5%). The volumes of nonferrous metals mined in Argentina, Colombia, and Ecuador are relatively small although all three countries have experienced an exploration boom in recent years. The following are profiles of the South American countries with the largest nonferrous metals mining outputs.

Chile

Chile is the number one producer of copper in the world and is an increasingly large producer of gold and other minerals. Chile=s total mining exports of $7.8 billion comprised 48% of the country=s 1996 export total. Copper led with exports worth $6.45 billion (US DOC, 1996).

Chile=s total copper production reached 2.49 million tons of fine copper in 1995, 26% of the world=s total. It is projected to exceed 4 million tons of fine copper annually by the year 2000, when it will represent 33% of worldwide production. Chile=s reserves of fine copper total about 180 million tons, 28% of world reserves (US DOC, 1996).

CODELCO (Chilean National Copper Corporation) produces more than half of the country=s copper, although the new private mines are quickly catching up. Chile has some of the largest mines in the world and a sizable small mines sector, but has only few mines of intermediate size.

Peru

The diversified Peruvian mining industry is big by world standards, with annual sales well over $2.3 billion (US DOC, 1997a), mostly to world markets. The mining industry contributed about 5% to the GDP and accounted for over 43% of all Peruvian exports in 1994. Favorable legislation, government guarantees for investors, enormous potential for gold and copper mining, and a skilled workforce have contributed to the tremendous growth in this sector. Production grew by 5.2% in 1996 after growing 8.5% in 1995. Copper and gold output recorded the highest increases, 18.1% and 12.2% respectively. Silver output grew by 13% from 1994 to 1996 (US DOC, 1997a). Forecasts through the year 2000 project $6.6 billion in new investments in this sector.

Privatization and the influx of foreign direct investment continue to change the industry=s structure. Since 1991, the government has privatized 14 mining enterprises worth over $627 million and there are obligations for future investments of more than $1.4 billion. In spite of the failure to privatize the state-owned giant, Centromin Peru, foreign companies continue to flock to

Peru through participation in the privatization process and the exploration rush that began in 1993 (US DOC, 1995).

Mining operations vary greatly both in size and type, ranging from large open pits to small and medium-sized polymetallic underground and surface mines. About two-thirds of Peruvian mineral production comes from large enterprises. Southern Peru Copper Corp. (SPCC) is Peru=s largest mining company, accounting for over 66% of the country=s copper production. It is the largest private firm in the sector in terms of sales with $721.8 million in 1994 (US DOC, 1995). Yanacocha S.A., a majority-owned gold operation of Newmont Mining (USA), is a large, modernized, and efficient mining operation that has transformed gold production in Peru. It accounts for 20% of all gold production in the country. About a quarter of Peru=s mineral production comes from privately owned medium-size mining enterprises and the rest comes from informal gold mining.

Bolivia

Mining is the most important sector in the Bolivian economy, generating almost 50% of the country=s foreign exchange. Bolivian mining has historically been dominated by tin, although its importance has recently declined. A modest local private sector (the Medium Miners Association) accounts for about half of the country=s tin production. Official gold exports grew by 55% in 1994 and are the largest source of export revenue, accounting for nearly one-third of Bolivia=s minerals trade (World Bank, 1996). Small-scale informal operations produce significant amounts of gold, most of which is not officially recorded. The production of zinc and silver has also risen in recent years.

Brazil

Brazil is an important producer of aluminum and gold. Brazil=s mineral reserves are enormous but production has grown only slightly in recent years. The exploration and mining investment fell sharply between 1988 and 1994 to about one-third of the level of the early 1980s due to the economic turmoil (World Bank, 1996). Therefore, even current production levels could become unsustainable.

Metals mining in Brazil is dominated by one company, Companhia do Vale do Rio Doce (CVRD) which was recently privatized in the biggest-ever privatization sale in Latin America. CVRD accounts for about 20% of the total sector output. International companies hold minority shares in some medium-sized enterprises. Informal (Agarimpo≅) gold mining involves some 300,000 miners and causes severe environmental degradation by mercury contamination and mudslides.

Venezuela
Venezuela is an important producer of bauxite ore and has the potential of increasing its gold production. The state-owned CVG Bauxilum has a monopoly on bauxite production, which is expected to rise from 5.6 million metric tons in 1996 to 10 million metric tons in 2002 (US DOC, 1997b).

There is little participation by local private enterprises in Venezuelan mining. Some foreign investors are actively involved in gold exploration and mining, but about half of Venezuela=s annual gold output is produced by small-scale miners operating without permits. The Venezuelan Mining Chamber estimates that between 40,000 and 60,000 informal miners are operating in Venezuela=s southern Bolivar and Amazonas States.

1.3 DRIVERS FOR ENVIRONMENTAL IMPROVEMENTS IN THE MINING INDUSTRY

This section describes internal and external factors forcing South America=s mining companies to improve their environmental performance. Incorporating environmental considerations in a mining operation can (1) save raw materials and energy and increase the product output through improving process efficiency; (2) help the company to comply with domestic environmental regulations; and (3) improve the company=s competitiveness in the international export market.

1.3.1 Operation Efficiency

The massive volumes of material processed in mining make it unique among industries. Most ore is well over 95% waste. With this high waste ratio, operating efficiency has always been critical to economic success. This holds for mining, ore processing, as well as the subsequent metallurgical processing and refining.

There is not always a clear distinction between pollution control and pollution prevention in the mining industry. When the material being recovered can be reused or sold as product, the overall efficiency of an operation increases. In other cases, more efficient processing reduces the need for pollution control technology. Measures that increase process efficiency and reduce the environmental impacts of mining, processing, and refining operations may bring the following financial benefits:

< recovery of valuable materials,
< reuse of valuable materials,
< reduced energy costs,
< reduced costs of wastewater treatment and/or air pollution control,

< reduced costs of waste disposal,
< reduced penalties from regulating agencies, and
< reduced liabilities from affected communities.

1.3.2 Environmental Laws and Regulations

Most South American countries regulate environmental protection in the mining industry by means other than mining-specific laws (e.g., mining codes). Virtually all the countries have environmental legislation but in most cases these laws are framework laws which require the development of industry standards and compliance procedures.

Environmental quality standards are still being developed in many South American countries. Where such standards exist, they are usually general sets of values adopted from international guidelines or foreign legislation that have not been adapted to local conditions due to the lack of relevant background information. For example, Chilean air and water quality standards are modeled after U.S. EPA regulations.

Environmental Impact Assessment (EIA) promises to become a powerful legal tool affecting mining enterprises at the feasibility stage of their activities. The EIA concept has been incorporated in the legislation of most South American countries. The EIA requirement went into full effect in Chile in 1994, and now all new projects must submit either a Declaration of Environmental Impact or an Environmental Impact Study, depending on the magnitude of potential environmental impacts. In Brazil, EIA is a prerequisite for environmental licensing of any activity exploiting mineral resources. Its criteria and implementation guidelines were promulgated in 1986 and amended in 1990 by the national environmental agency. The Environmental Impact Report (RIMA) for mining operations is required to include a Plan for Recovery of Degraded Areas (PRAD) with a description of site mitigation measures to be approved by the competent state environmental agency. Peru is currently developing special guidelines for the implementation of EIA in the mining industry.

Enforcement of environmental regulations varies in intensity, but with strengthened inter-agency coordination is gradually improving in many countries of the region. Peru=s Environmental Management Program (PAMA) may become a model for other countries= enforcement efforts. It requires mining companies to conduct environmental audits of their operations, to propose plans for improvements to meet environmental standards within legally determined time limits, and, after approval of the plan, to implement the plan and monitor and report results regularly.

Market-based environmental incentives are only starting to be used in South America. Chile=s environmental law authorizes the use of such economic instruments as pollution charges, tradeable permits, and user fees. In Argentina and Bolivia, there are tax incentives for investments in environmental improvements. The expanding use of economic incentives for

enforcement purposes will affect the costs of mining operations and give mining companies an additional reason to minimize environmental impacts from their operations.

1.3.3 Market Pressures

More mining firms now see environmental management as being strategy-driven rather than compliance-driven. The mining industry has realized that to stay competitive, it needs to integrate environmental considerations into its long-term business planning. The following commercial factors are becoming increasingly important influences on mining operations in South America:

Growing Acceptance of International Environmental Standards
The use of voluntary international standards for trade relations is becoming more and more widespread. The World Trade Organization (WTO) officially favors application of international standards in its agreement on Technical Barriers to Trade. The ISO 14000 standards and a more stringent Europe=s Eco-Management and Audit Scheme (EMAS) set forth basic requirements for an effective environmental management system (EMS). Since South American mining industries are mainly export-oriented, they may eventually be affected by these standards. Importers of South American minerals may come to expect ISO 14000 certification of their suppliers. Even though ISO 14000 is voluntary, market pressures encourage certification, since registration under the ISO 14000 series is a way to demonstrate that a company has a system aimed at achieving environmental performance objectives. ISO 14000 has already attracted a lot of attention in the mining sector in South America. The Chilean mining industry has been a leader in EMS implementation. For example, the publicly-owned CODELCO mining company aspires to qualify for ISO 14000 certification in 1998.

Adoption of Environmental Standards by Multinational Firms
International mining enterprises have realized the advantage of having long-term internationally acceptable environmental rules. They understand that their self-interest is served when they undertake environmental improvements. Local branches are required to adhere to guidelines issued by company headquarters. Competition between multinationals and local mining companies can accelerate considerably the process of environmental reorientation of the mining industry in South America.

Environmental Performance Requirements of Free Trade Agreements
The trade blocks in South America are increasingly addressing environmental issues. The two most important trade agreements in South America are the Andean Pact which consists of Bolivia, Colombia, Peru, and Venezuela; and the Southern Cone Common Market (MERCOSUR) which includes Argentina, Brazil, Paraguay, and Uruguay. Chile has an associate

agreement with MERCOSUR. In addition, MERCOSUR and the European Union are negotiating an agreement to increase economic cooperation in the short-term, with the ultimate goal of forming an inter-regional association. Many South American countries have concluded bilateral agreements with the U.S. and other developed countries. Many of these trade agreements impose environmental performance standards on South American exporters which have a direct impact on the mining industry.

Increased Public Awareness of Environmental Issues

The mining and mineral processing industries are often viewed negatively by the general public due to its heightened awareness of the potential effects of mining activities on human health and the environment. Companies that demonstrate through their environmental improvements that they are self-regulating, environmentally responsible corporate citizens will improve their public image and overall business profile.

CHAPTER 2
TYPICAL WASTES AND BEST MANAGEMENT PRACTICES IN MINING OPERATIONS

Mining operations in the nonferrous metals industry are of three types: underground mining, surface mining, and placer mining. This chapter briefly describes these three basic methods and some of the environmental issues associated with each. It then discusses the typical wastes generated in metals mining and the best management practices (BMP) for minimizing the environmental impact of these wastes. A table listing the BMPs for each type of waste is presented at the end of the chapter.

2.1 UNDERGROUND MINING

Underground mining refers to the extraction of ore from beneath the surface of the earth. A decision to use underground mining methods is based on economic profitability criteria (e.g., minerals may be located beyond the depth at which surface mining is economic), and on the size, dimensions, and distribution of the ore, etc. Several methods are used for underground mining and variations and combinations of methods are common. The choice depends primarily on the characteristics and strength of the ore and wall rock. These methods fall into three categories:

2.1.1 Naturally Supported Openings

These methods are used when strong ore and wall rock are present, permitting the stopes to remain open, essentially by their own strength, during ore extraction. These relatively low-cost methods of mining include: 1) open stoping, 2) sub-level stoping, 3) vertical crater retreat, 4) room-and-pillar mining, and 5) shrinkage stoping.

2.1.2 Artificially Supported Openings

These methods are used when ore and wall rock are not strong. Waste material, timbers, or mechanical means are used to keep the stopes open during mining. After the extraction

of the ore, the stopes are either filled to maintain stability or allowed to cave. These more expensive methods include: 1) cut-and-fill stoping, 2) square set stoping, 3) longwall mining, and 4) top slice stoping.

2.1.3 Caving Methods

These methods are used where there are large ore deposits with weak ore and wall rock that will collapse as the ore is removed. They have a high ore recovery when the ore is fractured enough to be handled in draw points. Capital investment is high but caving methods are low-cost. They include: 1) sub-level caving, and 2) block caving.

Underground mining does not create the volumes of overburden found in surface mining, although sometimes waste rock must still be brought to the surface for disposal. Underground mining usually involves a large capital investment and a higher production cost per ton of ore than surface mining.

2.2 SURFACE MINING

Surface mining strips away the overburden to expose the underlying minerals. These days surface mining accounts for a large portion of coal mining activities in the United States. Surface mining for coal, phosphate, and other industrial minerals is called Astrip mining.≅

In general, there are four basic unit operations common to most surface mining operations: drilling, blasting, loading, and hauling. Surface mining usually requires extensive blasting of both overburden and the ore. If the rock types are soft enough to permit excavation without blasting, the first two unit operations may not be performed.

There are three general methods of surface mining, with variations within each: open-pit mining, contour mining, and area mining.

2.2.1 Open-Pit Mining

This method is often used where large tonnages of ore are found relatively close to the earth's surface. Excavation often takes the shape of an inverted cone. One important economic criterion for open-pit mining is the amount of overlying waste that must be removed to extract the ore. The amount of waste to the amount of ore ratio is referred to as the stripping ratio.

Open-pit mining is the primary method for mining copper, gold and silver in the United States. A major issue in open-pit mining is the removal of the water that collects in the pit bottom because of rainfall and natural seepage.

2.2.2 Contour Mining

This method is practiced commonly in mountainous terrain where the ore outcrops on the mountain slopes. Mining generally begins by removing the overburden above the ore deposits, starting at the outcrops and proceeding along the hillside. The most popular and environmentally acceptable method of contour mining is haulback mining. In a typical operation, an adjacent hollow is selected and carefully prepared to receive the overburden of the first section cut into the hillside. The ore deposits are exposed and mined from the first pit. The mining then proceeds to an adjacent section, or to the two adjacent sections on either side of the first cut if two pits are to be in simultaneous operation. Haulback mining permits the reclamation of the back-filled sections by grading, replacing the topsoil, and seeding with grasses. These operations are performed on a continuous cycle along with the removal of the overburden and ore. Problems associated with water-quality control, such as acid mine drainage, can be minimized by selective replacement of toxics.

2.2.3 Area Mining

This method is used mostly where the terrain is flat or only slightly rolling and where the mine site includes large stretches of land. The first cut results in a long pit with a high wall on both sides of the pit. Overburden from this first pit is stored to be available to fill the final cut. A second cut is started adjacent to the first cut, into which the second cut=s overburden is placed. Strip by strip , the mining thus proceeds across the property.

Surface mining is safer than underground mining because the miners are not exposed to such potential hazards as roof falls and rock bursts, to explosions caused by methane gas or dust ignitions, and to lung related problems caused by long-term exposure to dusts.

2.3 PLACER MINING

Placer mining refers to the exploitation of placer mineral deposits for their valuable heavy minerals. Placer mineral deposits consist of detrital natural material containing discrete mineral particles. They are formed by chemical and physical weathering of in-place heavy minerals, which are then concentrated through the action of wind or moving water.

The two major environmental concerns associated with placer mining are water pollution and land disturbance. Both the mining and the processing of placer minerals require a great deal of water, and, once used, this water contains large amounts of suspended solids. If the water is allowed to run off into streams, these solids can have an adverse impact on the environment. In suspension they can harm aquatic habitats and when settled out can clog waterways and choke off irrigated crops. In order to minimize the impact of the suspended solids of the wastewater, a series of settling ponds is often used; the water is later recycled to the extraction process.

Since most placer mining is surface mining, land disturbance is unavoidable, especially where dredging operations create vast piles of coarse waste rock. Land reclamation methods include re-vegetation, creation of new recreational or agricultural areas or, in urban areas, creation of new industrial sites.

Gold and tin commonly occur in placer deposits and so are often mined by placer mining methods.

2.4 TYPICAL WASTES

Typical wastes from the mining processes can be divided in four main categories: solid wastes, liquid wastes, air pollution, and hazardous wastes resulting from blasting, drilling, and equipment maintenance.

2.4.1 Solid Wastes

The most common solid wastes generated by the mining operations are overburden and waste rock, which are usually disposed of in piles near the extraction site.

Overburden is inert material located on top of an ore deposit. This material typically consists of surface soil and vegetation that needs to be removed in order to access the ore deposits. Overburden material is usually stored in piles located close to the extraction site. Some environmental concerns of overburden include visual impact, pile stability (e.g., acid drainage formation and mechanical/geotechnical issues), dust emissions, and runoff of solids.

Waste rock typically includes both the rock removed to access or exploit the ore deposit and the rock embedded within the ore or mineral deposit. Storage and disposal methods are similar to those used for overburden. The main difference is that a certain amount of the waste rock is reused in construction and as backfill to underground mining operations. Reuse of waste rock is

of limited utility in reducing overall disposal problems because of the remote locations of the mines, the acid-generating potential of the waste rock, and the large volumes involved.

2.4.2 Liquid Wastes

These type of wastes can be a significant problem at many mines. Continuous pumping and monitoring of great volumes of water are usually required.
Mine water is the water that is removed from the mine to gain and maintain access to the ore deposit. It can originate from precipitation and/or from a groundwater aquifer intercepted by the mine. One of the major concerns regarding mine water is the potential for acid generation and metal mobilization in waste associated with mining operations.

In surface mining operations the volume of mine water depends on the ingress of groundwater and the precipitation onto the surface area of the pit. The control systems depend significantly on the topography of the site. Mine water is usually collected at the lowest point and pumped out of the mine; if the mine is located on hillsides, ditches can be used to intercept the runoff.

For underground operations, the volume of mine water is significantly influenced by the local hydrogeologic conditions, the infiltration of surface water into the mine. Mine water is pumped to the surface from collection sumps where suspended solids are decanted. It is recommended to collect all mine water at a single point where it can be directed to the process, as process water, to the environment, or to treatment.

Acid drainage is common in areas where mine openings intersect the water table and where the rocks contain iron or other sulfides. A severe pollution hazard in many mining operations, it occurs when sulfide minerals, catalyzed by bacteria, oxidize to create ferrous iron and sulfuric acid, often accompanied by cations of a variety of other metals, as well as anions. It is called acid mine drainage when it occurs inside the mine, and acid rock drainage when it occurs on waste rock and tailings piles. More information regarding acid mine drainage is included in Chapter 4.

2.4.3 Air Pollution

Air pollution is a significant type of waste during excavation of the ore deposits and transportation from the mine to the ore processing facility. Dust particles are the main concern in air pollution related to mining and extraction operations. The main air pollutants are dust particles and exhaust fumes.

Dust particles are generated at many stages of the mining process and can result in great environmental hazards depending on site conditions, management practices, and type of ore being mined. The most effective way to control or minimize dust emissions is to increase the

surface moisture in places where dust is produced. Dust emissions can be categorized as either point source dust or fugitive dust.

Common sources of dust particles are: ore and waste loading points; trucks, railroad cars, etc.; ore chutes in haulage systems; exhaust from dedusting installations; waste dumps; ore stock piles; haulroads; road traffic; blasting, drilling, and hauling equipment; and rock crushers.

Exhaust fumes are usually produced by diesel engines and blasting agents. These fumes can be a serious hazard to the environment and to the health of those working in underground mines.

2.4.4 Other Wastes

The wastes considered in this category are generated mainly by blasting and drilling and by the transporting of ore from the mine to the ore processing facility. These types of wastes are usually harmful to subsequent mineral beneficiation processes and should be collected and treated separately. These wastes include explosives; fuel, lubricants, and hydraulic oils; and hydraulic fluids and batteries.

Used for blasting operations, explosives contain such constituents as ammonium nitrate, trinitrotoluene, and nitroglycerine that are potential pollutants to the soil and water bodies.

Fuel, lubricants, and hydraulic oils are used for engines, power plants, and lubrication. They are also used by mobile rigs when drilling holes in the rock to locate the explosives in blasting operations. These wastes contain benzene, toluene, and other aromatic compounds that are known carcinogens.

Hydraulic fluids and batteries are used by the loading and hauling equipment that transport the ore to the beneficiation mil for processing. This equipment includes trucks, rail cars, and conveyors. The hydraulic fluids contain glycol ethers, while the batteries contain sulfuric acid, lead, and other compounds.

Table 2-1
Typical wastes from Mining Operations and Best Management Practices

Typical Mining Wastes	Best Management Practices
Solid Wastes	< Backfill into dry mine workings < Maximize its use in reclamation < Incorporate drainage systems into dump foundations < Selective placement/covering of acid generating materials < Avoid or minimize the exposure of sulfide minerals
Liquid Wastes	< Segregate/separate flows with respect to water contaminants present and the final treatment and disposal methods < Evaporation and re-use in processing operations < Run-on and runoff control measure, such as berms and ditches < Neutralization/precipitation or other treatment practices prior to discharges < Monitor discharges and surface water quality < Plan mine water containment units to minimize potential for water recharge < Collect and monitor seepage, drainage, and runoff < Use run-on controls to minimize potential for infiltration < Segregate and cover reactive waste rock with non-reactive materials < Segregating clean and contaminated drainage
Air Pollution	< Properly design ventilation systems < Water spraying the ore < Water spraying on roads used for transportation of the ore < Use of dust suppressants < Incorporation of water and wetting agents in places where dust may be produced < Use of totally hermetic storage areas when dealing with fine dust < Separate the dust from the air by physical/mechanical means (e.g., bag filters, wet scrubbers, electrostatic precipitators, etc.) < Place a layer of crushed rock on the surface of roads
Other Wastes	< Clean-up of blasting residuals < Maintain storage containers properly

2.5 BEST MANAGEMENT PRACTICES

This section presents the best management practices (BMP) recommended that apply generally to all types of mining operations. BMP are outlined for each major activity or site where wastes are generated or treated: 1) access and haul roads, 2) general mining and extraction, 3) solid waste management, and 4) settling and process water ponds. At the end of the section, a table summarizing BMPs for the different types of waste is presented.

2.5.1 Access and Haul Roads

Best management practices should be selected to minimize soil movement and to reduce the volume and velocity of runoff water. BMPs can help provide adequate drainage on roadways so that the road surface, side slopes, and borrow areas can be stabilized and do not contribute sediment to surface water. Some BMPs for access and haul roads are:

< Avoid locating roads on steep slopes where shallow, coarse textured soils exist. It is hard to stabilize fills in these regions and the road will be subject to surface erosion and slope failure.

< Avoid locating roads in landslide areas, narrow canyons, or in areas where there are tension cracks and high cut banks.

< Roads should be located on natural benches, ridges and rock formations that tend to dip into the slope. Road widths and grades should be kept to a minimum.

< Design roads to match natural contours. This should reduce the number and size of cut and fill slopes.

< Special geologic factors that should be considered in evaluating slope stability include groundwater conditions and attitude of structural controls, such as bedding planes, faults, and joints, relative to ground slope.

< Install drainage and sediment collection systems prior to beginning road construction. These structures should be placed adjacent to the proposed route to catch sediment-laden runoff or to divert surface water away from the roadway.

< Reestablish vegetative cover on disturbed land as soon as possible during the construction phase and after it is completed to help reduce erosion.

< Install drainage facilities in the roadway to protect road work as it is completed.

< Routinely inspect and clean sediment control structures and minimize the amount of bare soil.

< Blend the final construction contours with surrounding topography to maintain natural drainage patterns where possible.

2.5.2 General Mining and Extraction

These general BMPs cover activities ranging from mining site development to actual mining operations. They can be applied to any of the different mining methods discussed in this manual, depending upon individual circumstances.

When establishing the boundaries of a surface mine, a buffer zone of undisturbed vegetation must be left between the area to be worked and any existing stream channel or live body of water.

During the initial site preparation/construction phase of any surface mining operation, limit the amount of unvegetated ground. Best management practices should be installed prior to construction to limit and control runoff from unvegetated areas. Some BMPs used for this purpose are: straw bale barriers, slit fences, brush sediment barriers, sediment ponds, and log and brush check dams.

Design of open pits should include measures which prevent surface water from entering the workings. This can be accomplished by minimizing the workings near surface waters or by diverting streams and/or other surface water around developed areas. There may be situations where it would be better to allow surface water to flow into a pit after mining is complete, rather than to create or maintain diversions around the pit. If water enters the pit, the pit may act as a recharge area to groundwater and filter out sediments. Some BMPs used for these this purposes are: diversion dikes and stream alteration techniques.

Topsoil and overburden should be segregated and stockpiled for use in reclamation. Topsoil stockpiles that will not be used within a year should be graded and seeded to prevent wind and water erosion and to help keep nutrients in the soil. Limit unnecessary materials handling by locating stockpiles away from potentially affected lands.

Each phase of the operation should be reclaimed concurrently during mining to help reduce erosion and water quality impacts. This will also spread reclamation costs over the life of the mine. During operations, inspect and clean sediment control structures to maintain their efficiency.

2.5.3 Waste Management

Best management practices for solid waste dumps are the same for all types of mining. Some of the BMPs in waste management are:

< Locate waste dumps or spent ore dumps away from surface waters, springs, seeps and wetlands. If this is not feasible, water should be diverted around the dump and/or a drain field should be installed under the dump. The drain field or diversion dike should discharge into a settling pond.

< Enhance the long term mass stability of a dump by locating it and constructing it so the potential for failure is minimized. This can be done by evaluating the geologic nature of the material to be placed in the dump and locating the dump in a geologically stable area. Avoid faults, dense joint systems, and landslide areas. Locating dumps in flat topography is preferable to sloped terrain.

< Where acid mine drainage may be generated by oxidation of sulfides, prevention measures should be taken. These measures may include impermeable caps and liners, surface water diversions and/or blending acid consuming materials such as limestone with wastes. Where preventive measures are impractical, water treatment will be necessary until acidic discharges meet quality standards.

< Any water that runs off a surface of a dump should be diverted behind siltation berms, into catch basins, into sediment ponds, or through silt fences.

2.5.4 Settling and Process Water Ponds

The purpose of these BMPs is to ensure that settling and process water ponds for placer and surface mining are designed, operated and reclaimed so that pollution from outside water sources is minimized and water quality is protected. Settling ponds are used for process-contaminated water derived from floating or dry land dredges, from washing plants, from sluicing or other forms of placer mining, and from surface mining, which can deposit significant amounts of sediment into surface water. Some of the BMPs in this category are:

< Ponds should be located in a geologically stable area, at least fifty feet away from streams and other surface waters.

< Ponds should be kept out of active flood plains. This will eliminate the need for diverting streams around the ponds and will reduce reclamation requirements.

< Ponds should be located so all surface water may be diverted around them. Stream alteration techniques are widely used for these purposes, along with diversion dikes/ditches, and interceptor trenches.

< Ponds should be located so groundwater seepage into the pond and/or leakage from the pond into the subsurface is kept to a minimum. This can be done by lining the pond with bentonite clay or other impermeable liners, or by installing cut-off trenches around the pond to decrease groundwater infiltration. If the pond is lined, a drain field may be installed below the liner to reduce hydrostatic pressures against the liners caused by the groundwater.

< Several settling ponds are often preferable to one large pond. Water can be retained for longer periods in multiple ponds, thus allowing sediments more time to settle out before water is discharged. One pond in the series might be the principal sediment trap while another could be used to hold Aclarified A water that could be recirculated through a processing plant.

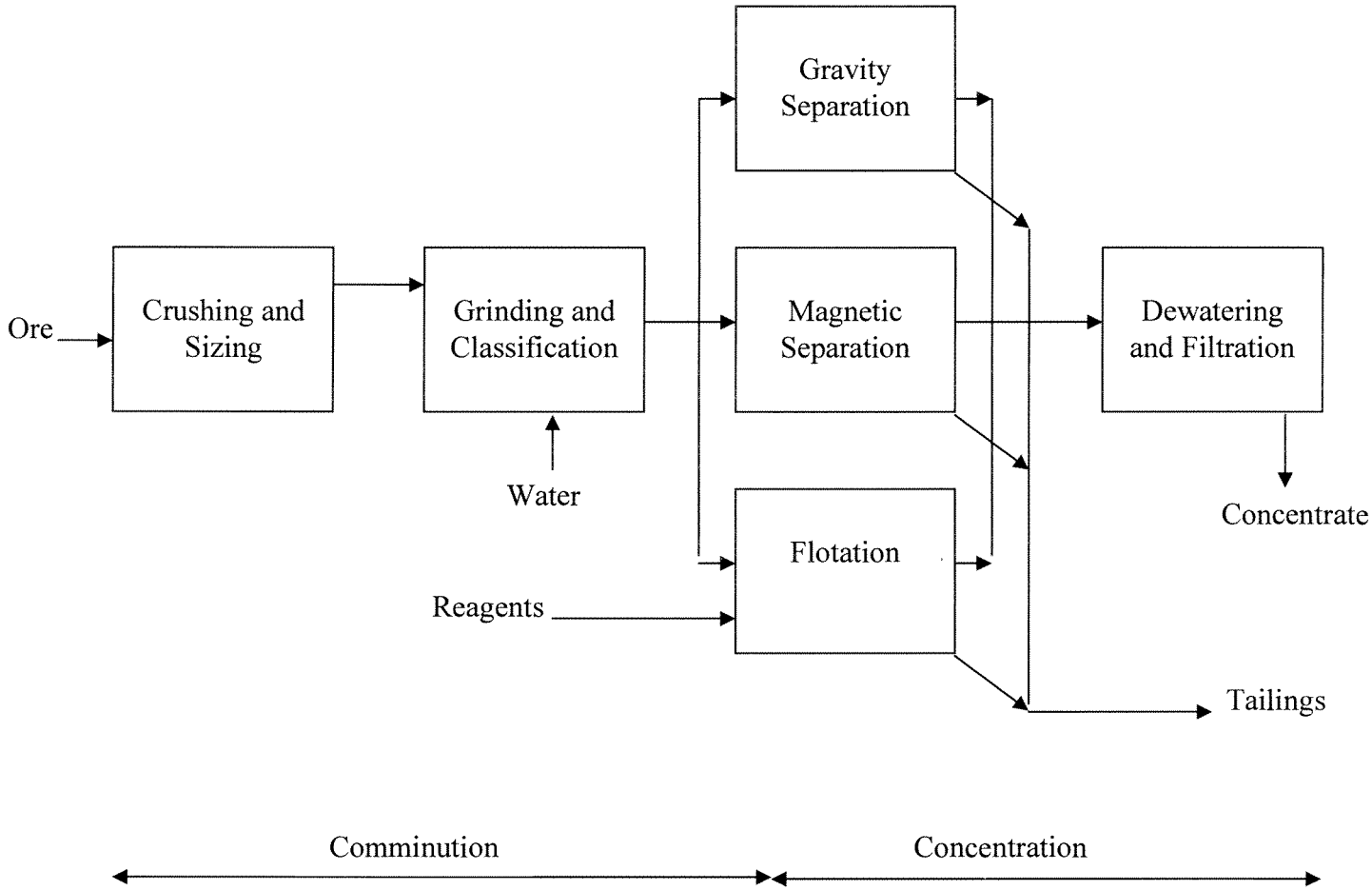
CHAPTER 3
TYPICAL WASTES AND BEST MANAGEMENT PRACTICES IN ORE PROCESSING OPERATIONS

Ore processing, also known as ore beneficiation or mineral processing, is the first phase of treatment (see diagram) of the ore after the mining operations. Its main objective is to prepare the ore for subsequent stages in the overall metal extraction process, such as smelting and refining. It serves to remove unwanted constituents and/or to alter physical properties of the ore, such as particle size and moisture content. The output of the ore processing stage is a concentrate of the metallic minerals that require further processing. Ore processing usually consists of three main steps: comminution, concentration, and de-watering.

This chapter will present the unit operations involved and identify the typical wastes produced at each stage of ore processing. Also discussed are best management practices (BMP) to use at each stage to prevent or reduce environmental harm. Briefly mentioned is the leaching process used to recover some metals as part of ore processing and as a pre-smelting step. The final section focuses on the waste materials remaining at the conclusion of ore processing and describes the BMP for dealing with these wastes. For a detail flow diagram of the ore-processing phase, please see attached annex.

A basic flow diagram of the beneficiation steps is shown on Figure 3.1.

Figure 3.1
Simplified Flow diagram of the Beneficiation Stage of Mining



3.1 COMMINUTION

Comminution is the first step of the ore processing operations. It consists of a series of unit operations that reduce the particle size of mined ore. The objective is to liberate the desired ore minerals from the undesired waste minerals, or gangue, enabling subsequent concentration operations to produce concentrates of the ore mineral (s) of as high a purity as possible. It is divided in two steps: primary comminution, which involves crushing and sizing of the ore, and secondary comminution, which involves grinding the ore into the desired particle size and a second sizing operation.

During primary comminution, jaw or gyratory crushers are used to crush the larger rocks, then cone or roll crushers reduce the particle size of the ore further. Sizing is carried out using grizzlies and screens.

In the second step, the crushed rock is fed into a mill where is ground into fine particles. The ore is then classified, using equipment such as hydrocyclones, to control particle size distribution. Oversized particles are reground.

The main wastes from the comminution process are dust and process water. The best management practices for reducing the environmental impact of these wastes include:

< recycling the zinc mantle liner pieces in the secondary crushers,
< spraying the ore with water,
< recycling the water used/produced
< using dust suppressants,
< incorporating water and wetting agents in places where dust may be produced, and
< removing the dust from the air by physical/mechanical means (e.g., bag filters, wet scrubbers, electrostatic precipitators, etc.).

3.2 CONCENTRATION

The concentration stage of ore processing serves to separate the desired ore mineral from the gangue (unwanted mineral/rock), which is then discarded as waste. It usually involves several steps, especially if the ore contains more than one economically attractive commodity (metal) and each must be separated for further processing. Three main methods are used to concentrate the ore. These methods can be used alone or combined depending on the type of ore and the final metals that will be produced.

Gravity separation is not widely used today for nonferrous metal concentration, except in some gold, silver, or tin operations or as a pre-concentration or Aroughing≅ stage of beneficiation for other ores. The effectiveness of the separation depends on the difference in specific gravity between the minerals to be separated (the greater the difference the better the separation). A uniform particle size is preferred to achieve good separation efficiencies.

Flotation is the major concentration method used to treat all base-metal sulfide ores. In flotation, the desired minerals are induced to attach to air bubbles through the selective adsorption of surface active chemicals called reagents. The mineralized bubbles collect at the top of the machine as a froth, which is collected and sent to the smelter. The undesired minerals do not attach to the air bubbles and can be removed from the flotation machine as a water slurry for further treatment or disposal. Several types of reagents are used to enhance the performance of flotation systems: frothers, collectors, and conditioners.

Magnetic separation, the third method of concentration, separates magnetically susceptible mineral from gangue minerals by applying a magnetic field. The electrostatic process uses a high-voltage electric field to separate materials of different electrical conductivity.

Best management practices to use for concentration include:

< Installing a collection system for liquid spillage and for directing the effluent to the tailings disposal system

< Using new, more selective and/or more environmentally benign reagents. For example, non-toxic reagents may be substituted for cyanide compounds in base metal flotation operations (e.g., sodium sulfide/bisulfide, thiosulfate/hypophosphite/oxalates/sulfite or a lignin derivative may be used as alternatives to sodium cyanide)

< Using special holding tanks and piping for reagents

< Installing flotation process control equipment with sensors, computer elements, and control units. This will reduce the amount of flotation reagents required and improve both separation selectivity and recovery of valuable metals.

< Substituting lime or other less toxic reagents for the ammonia used in the ore processing circuits to maintain alkalinity.

3.3 DEWATERING

Final concentrate arrives at the dewatering stage as a dilute slurry containing large amounts of water. The concentrate is dewatered using two processes, thickening and filtration.

During thickening, the dilute slurry is held in settling tanks and the solids are allowed to settle, after which the excess water is discharged. Flocculants are usually used to help settle the finest and lightest particles. As water is removed, the dilute slurry becomes a thick pulp. Sometimes hydraulic cyclones are used in the thickening process. These use centrifugal forces to separate the liquids from the solids.

The final dewatering process is filtration, which extracts as much of the remaining water as possible.

3.4 LEACHING

There are five basic types of leaching operations. 1) Dump leaching extracts the metal by percolating leach solutions through low-grade waste. 2) In heap leaching, oxide ore is placed on a prepared surface such as asphalt; the solutions are collected and trapped behind a dam and pumped to a processing site. 3) In situ leaching is done in place, normally once the sulfide ore deposit has been mined out, with the leaching taking place in old abandoned mine workings that require little preparation. 4) Vat leaching requires that the ore be crushed; it is then placed into tanks or vats for leaching. 5) Agitation leaching entails crushing and grinding the ore, slurrying with water and reagents, and then leaching in stirred tanks (e.g., Pachuca tanks).

A relatively new technique, thin layer leaching, has been used with some success at several copper mines in Chile since 1980. The process combines two main steps: 1) curing, which involves sulfuric acid attack of a finely crushed ore, followed by a resting or Acuring≅ period, and 2) leaching, which is performed using normal leach procedures, spraying dilute leach solutions on top of a previously cured ore.

Some of the BMPs to use when leaching include:

< Designing dump leach units that fully drain to collection areas

< Locating leaching operations away from drainages

< Ensuring that pregnant and barren ponds and ditches are designed to hold all flows and any runoff up to the maximum reasonable storm event

< Recycling process waters

< Providing secondary containment for pipes that will carry leach solutions, so that impacts from pipe failures/spills can be minimized

< Using double liners and leak detection systems for all heaps, ponds, and drainage ditches

< Detoxifying heaps, dumps, and any spent solutions to reduce cyanide, acidity, and metal loadings

< Testing detoxified materials prior to disposal or mine closure to ensure that toxic chemical levels are reduced

< Collecting and testing seepage and runoff from spent ore piles; treating runoff/seepage as necessary; performing downstream water quality monitoring

< Providing biological treatment for cyanides, nitrates, and heavy metals

< Substituting thiourea, thiosulfate, malononitriles, bromine, and chlorine compounds for cyanide (under certain conditions)

< Substituting thin layer leaching for agitation leaching in copper processing, to reduce water use by as much as 75 % and to reduce fugitive dust generation

3.5 ORE PROCESSING WASTES

Although large amounts of water are needed in ore processing, the amounts of reagents used is small (usually less than a pound per ton of ore). In addition, reagents generally decompose when retained for a period in tailings ponds. The time required for separation of the solids is usually sufficient for the decomposition of reagents as well. In cases where acid-generating conditions in the pond are an issue, lime is sometimes added to reduce acidity and to precipitate the dissolved metals.

Large volumes of waste material is generated in ore processing operations due to the low concentrations of the desired commodity minerals in the ore. These wastes, mainly comprised of the gangue minerals, are disposed to ponds, usually in a slurry form called tailings. Tailings also contain residues of chemicals used in ore processing. Tailings usually consist of 40-70% water and 30-60% solids. The water can often be reused in the milling process, while the solids are usually permanently disposed in tailings impoundments. In some cases, the coarsest of the tailings solids may be used as a backfilled medium in underground mines. More about tailings handling will be discussed in Chapter 4.

Some of the BMPs regarding ore processing wastes are:

< Segregating wastewater flows according to water quality and final treatment and disposal method

< Evaporation and reuse of wastewater in processing operations

< Neutralization/precipitation or other treatment practices prior to discharging wastes

< Segregating clean and contaminated drainage

< Use of collection unit large enough to hold runoff from maximum reasonable storm event

< Use of natural and/or synthetic liners for units located in drainages and for any seepage/runoff collection sumps/ditches

- Maximizing the reclaim/reuse of tailings water
- Limiting use of mill reagents
- Providing adequate drainage of berms
- Including secondary containment of tailings pipelines
- Continuing ARD testing throughout operations and mine closure
- Collecting and treating runoff/seepage from outer slopes of impoundment
- Segregating pyrites and other sulfides from other gangue materials before discharge to tailings impoundments to reduce the potential for sulfuric acid formation.

CHAPTER 4
ENVIRONMENTAL ASPECTS AND BEST MANAGEMENT PRACTICES (BMPS)

This chapter includes the best management practices to minimize the potential impacts of mining activities on the environment, both during and after completion of operations.

4.1 WATER, RUNOFF, AND EROSION MANAGEMENT

Water is involved in almost every aspect of mine operations and its management is a major environmental concern. Potential sources of water pollution stemming from mining operations include drainage from surface and underground mines, wastewater from beneficiation, and surface run-off. Possible contaminants include acids, metals, sodium cyanide and mercury from gold recovery, process reagents, nitrogen compounds from blasting materials, and oil and fuel oil used for engines, power plants, and lubrication. All of these can create problems when they reach receiving water bodies.

The volume and the chemical composition of potentially contaminated waters vary depending on the type of mining operations, hydrology of the mine, nature of the ore, beneficiation process, concentration, tailings disposal method, and site location. Process effluent and surface water runoff, which has come into contact with mine facilities, usually contain suspended solids. Such materials may be part of the ore, waste rock, tailings, or the soil in the area of operations. Water pollutants have the potential to affect aquatic fauna and flora and may accumulate in animal tissues if not properly controlled. The toxicity of water contaminants depends on the nature and concentration of the pollutants in the water and on factors that moderate the bioavailability of metals, alkalinity, and hardness.

For open pit operations, the volume of surface water that accumulates in the pit depends on groundwater seepage, precipitation, and runoff into the pit. The water is normally collected in sumps in the pit bottom. For underground operations, the volume of mine water is influenced by the local hydrogeologic conditions, the infiltration of surface water into the mine, water used for

drilling and dust suppression, and water contained in tailings backfill. Mine water is frequently pumped to the surface from collection sumps where most of the suspended solids are decanted.

Runoff after rain or snowfall can contribute to pollution problems if not properly managed. Disturbances of the terrain created by open pit mining are usually susceptible to erosion, which can lead to silting. Roads used to transport ore and concentrates, ore stockpiles, and uncovered workshops are all sites that may become sources of water contaminants if adequate control measures are not undertaken during rainfall events.

4.1.1 Water Management

Whenever practical, surface runoff should be diverted away from mining areas and surface facilities. If conditions permit, the different waste water flows (mine water, surface water runoff, tailings from beneficiation) can be collected in a single point for a possible treatment prior to release to the environment; otherwise segregated collection and treatment should be used.

Pit Dewatering

Design of open pits should include measures which prevent surface waters from entering the pit. This can be accomplished by minimizing development near surface waters or by diverting streams around developed areas. Storm water directly contacting the pit and groundwater seeping into the pit should be directed to an inactive area within the pit for dewatering. Pit dewatering should not take place within an active area. Water removed from the pit may be:

< reused onsite, where possible
< donated for use offsite
< discharged into settling ponds
< applied to vegetated uplands

If a spill of hazardous materials occurs within the pit (e.g., oil or grease), the spill should be contained immediately to avoid additional contact with unimpacted waters. Impacted waters should be properly treated.

Truck Wash Facility Water Handling

The waste stream from the truck wash facility typically consists of hot water, detergents, grease, oil, and solids, especially road dirt. A high pressure water spray may be used to facilitate the cleaning process. Pretreatment of truck wash facility water should include primary settlement or traps to catch solids, followed by an industrial interceptor or oil/water separator. The traps should be cleaned on a periodic basis and properly disposed of. Truck wash facility water may then be directed into a settling basin for evaporation or reuse.

Reuse of Washwater

To reduce the amount of washwater that needs to be discharged, and to reduce water demand for the facility, washwater should be reused where possible. Clarified water from the settling ponds should flow down gradient to a holding pond for reuse. Water may be drawn from the holding pond to be used onsite for dust control, truck washing, or in the concrete batching operation. The water should keep being reused until its quality has deteriorated so much that it must be disposed of or treated. A water level measuring device, pump timer, or flow meter may be installed to monitor the amount of usage.

4.1.2 Runoff and Erosion Control

The quality of discharges from a mine site is a direct reflection of onsite sediment management. Expensive solutions to water quality problems can often be avoided by incorporating runoff and erosion control techniques into the mine development plan. Soil erosion can be minimized by the construction of mechanical structures and by revegetation. This section is concerned primarily with mechanical methods of erosion and sediment control. Table 4-1 summarizes practices used to control erosion and runoff and thus to reduce the amount of contaminated water that requires treatment prior to discharge offsite.

Table 4-1
Erosion and Runoff Control
Best Management Practices

Structure	Associated Management Alternative
Conveyance channels and ditches	Construct berms and ditches to divert run on and runoff away from natural drainages and slopes and into vegetated areas around the mine site
Water bars	Construct closely spaced water bars on roads susceptible to erosion
Water bars	Use water bars on access roads above the mine cut or other roads that receive only occasional use
Land application dispersal systems	Use land application for removing sediment from water. Turbid water is sent through dispersal systems that allow it to slowly soak into vegetated areas.
Roads	Elevate frequently used roads to keep runoff away from areas where it is most likely to pick up sediment
Roads	Make sure all roads are well covered with inert, durable, coarse rock of appropriate size and with good wear characteristics.
Floor of the excavation	On the pit or quarry floor, establish and maintain a slope that allows turbid water to

Structure	Associated Management Alternative
	drain toward a low point where it can be collected in a pond or a sump to allow solids to settle
Disturbed plant site area	In both excavation and processing areas, develop and maintain places that will readily contain runoff and precipitation
Excavation floor	When processing rock on the excavation floor, make sure adequate drainage is provided
Filter berms	Use filter beams built of porous materials such as sand and gravel or processed quarry rock that contains no 200-mesh or smaller material to remove sediments
Dry wells	Where allowable by local customers, use dry wells or infiltration galleries and horizontal subdrains to allow runoff to infiltrate into the ground rather than run off the site
Rock stockpiles	Regrade, reshape, revegetate, and otherwise protect areas that have the potential to produce runoff sediment
Rock storage areas	Minimize the currently disturbed area by maximizing the area reclaimed over time
Disturbed plant site area	Minimize the amount of water requiring treatment by isolating ground water from contamination by runoff
Buffer strips	Where practical, establish and maintain stable vegetated buffer strips between disturbed areas and any natural drainage

Source: Best Management Practices for the Rock Products Industry, Environet Inc, 1997

For most mine sites, a drainage control system can minimize surface water discharges. Controlling runoff and potential erosion requires an integrated watershed management approach Best management practices are likely to change over the life of the operation. Specific techniques appropriate to a given site depend on climate, topography, and the erodability of the material present.

The rate of erosion is affected by four main factors: climate, soil characteristics, topography, and vegetation. The two most important things that can be done to minimize erosion are to install erosion-control mechanisms and to slow surface water runoff velocities in the disturbed areas:

< Covering steep slopes with plastic sheeting or mulch and/or revegetating bare areas reduces erosion.

< Gravel on berms or other disturbed areas can significantly reduce sediment movement during heavy rains.

< Runoff velocities can be controlled by retarding flow and/or breaking up or minimizing slope length.

< Retarding flow on a slope can be accomplished with organic debris or geotextiles. Small, discontinuous terraces, berms and furrows on the overburden cut above the mine or on reclaimed slopes can effectively slow runoff and decrease sediment transport.

< Benches cut in overburden or other unconsolidated material likely to erode should be sloped into the hillside and away from the center of the bench to allow drainage.

< Runoff velocities can also be reduced by integrating velocity control structures directly into the drainage ditch system. These structures may be used in conjunction with settling ponds.

4.1.3 Passive Control of Runoff

Conventional runoff control methods tend to concentrate flows using ditches, berms, and ponds. The best strategy for runoff control is to divert runoff and overland flow around the mining site and back into the natural drainage and to isolate the source of the sediment. Passive runoff controls can reduce or eliminate suspended fines before they reach the settling pond system. These techniques rely on gravity to do their work. They are designed to disperse runoff at numerous locations rather than to concentrate flows, which then have to be treated to remove sediment. Surface water management should be used to prevent overland flow over any significant distance.

Keeping non-contact water separate from contacted water is the best way to minimize the amount of water that may have to be treated or contained. In some cases, passive controls of runoff may be sufficient.

Table 4-2 summarizes passive erosion and runoff control measures.

Table 4-2
Passive Erosion and Runoff Control
Best Management Practices

Structure	Associated Best Management Alternative
Conveyance channels and ditches	Use riprap, grass, or lined channels to reduce scouring and sediment liberation in conveyance channels and ditches.
Conveyance channels and ditches	Contour and diversion ditches should be used to direct surface runoff away from disturbed areas and to prevent rills and gullies from forming
Slash windrows and brush sediment barriers	Use slash windrows below roads, overburden and soil stock piles, and at other disturbed areas that have short, moderate to steep slopes.
Slash windrows and brush sediment barriers	Use brush sediment barriers on open slopes where flow is not concentrated to help prevent sheet flow and rill and gully erosion during heavy rains.
Straw Bales	Use straw bales as a temporary erosion control method. Correct installation of straw bales is essential. Straw bales are most practical below disturbed areas where rill erosion occurs from sheet runoff. Straw bales may be used in minor swales and ditch lines where the drainage area is smaller than 1 hectare and/or where effectiveness is required for 3 months or less.
Straw Bales	Use straw bales in conjunction with a check dam or filter berm constructed if sand or gravel for more effective erosion control than straw bales alone.
Silt fences	Silt fences may be used below disturbed areas where runoff may occur in the form of sheet and rill erosion. A silt fence is made of filter fabric that allows water to pass through. The fence is placed perpendicular to the flow direction and is held upright with stakes.
Erosion Control Blankets	Erosion control blankets can be used on steep slopes to control potentially severely affected areas. Erosion control blankets are made of artificial and natural fibers including jute, coconut husk fibers, straw, synthetic fabrics, plastic or any combination of these. This method is effective but costly so its use is usually restricted to small areas requiring very effective control to protect sensitive receptor areas.
Vegetation	Leave as much vegetation as possible undisturbed. This can be the most effective surface for preventing erosion and reducing surface water velocities.
Vegetation	If a new area must be cleared for mining, clear only the amount needed for the next phase of mine expansion.
Vegetation	Replace topsoil and replant mined areas as soon as possible
Vegetation	Stockpiles can be temporarily revegetated to reduce erosion.

Structure	Associated Best Management Alternative
Check dams	Use check dams to slow surface flow in ditches and to minimize downcutting
Filter berms	Use filter berms in channels with low flow velocities.
Trench subdrains and french drains	Use drains for runoff control, dewatering landslides and agricultural lands and stabilizing cut roads along slopes.
Infiltration galleries and dry wells	Use infiltration galleries at quarry sites or areas where natural infiltration of runoff is minimal. Use is practical only when volumes of runoff are small and grades prevent connection to a gravity flow subdrain

4.1.4 Settling Ponds

Most mine operations cannot rely solely on passive runoff control methods and must also employ settling ponds as an integral part of their water runoff management system. These flat bottomed excavations can range from small hand-dug sumps to larger ponds covering several hectares. Two types of settling ponds are commonly used: detention and retention. Detention ponds reduce the velocity of runoff, allowing sediment to settle before runoff moves offsite. Retention ponds are large enough to accept all runoff without surface discharge.

Ponds can be developed by building embankments or by excavating below grade. Excavated ponds are preferable because they are less likely to fail. Ideally, ponds should be situated at the bottom of a slope. Settling ponds provide the best method for allowing sediment to settle out of turbid water.

Ponds should be designed to maximize velocity reduction and storage time. A good rule of thumb is that the flow path of the pond should be at least five times the length of the pond. If ponds are to be placed in the lowest area of the watershed, several should be placed in a series. Ponds should be placed as close as possible to the areas likely to contribute sediment. For most mining situations, ponds should be designed to handle the runoff from at least a 25-year/24 hour event.

Settling ponds must be cleaned out regularly to remain effective. Spillways should be kept open and ready to receive overflow during large storms. Regardless of the method of sediment removal, all sediment removed should be placed in a stable location so that it will not enter waterways. The method of releasing water from runoff ponds can be critical to efficiency. Standpipes, spillways, and infiltration are the most common release methods. In some places, additional treatment is required to reduce the turbidity of runoff to acceptable levels before it can be discharged to public waters. When runoff contains abundant particles too fine to settle using conventional pond treatment, land application is the treatment of choice. Alternative treatment methods include the addition of flocculants or the use of water clarifiers.

Constructed wetlands may be a valuable and effective option in situations where final improvements to water quality are necessary to meet discharge or receiving water criteria.

4.2 TAILINGS, WASTE ROCK, AND OVERBURDEN MANAGEMENT

Tailings from beneficiation plants usually consist of a slurry which contains particles of ground materials (gangue minerals, minor amounts of valuable minerals) suspended in water. In modern systems, tailings are discharged into a tailings pond where solids are allowed to settle and clarified water is recycled for reuse. Tailings pond effluent contains suspended and dissolved solids composed of elements of the ore treated in the plant, trace metals in solution, sulfide minerals, and chemicals used for mineral recovery.

Mining sites also generate large piles of overburden and waste rock. Dumps and stockpiles are created to temporarily or permanently store overburden, waste rock, and other material of no economic value.

4.2.1 Tailings: Best Management Practices

Best management practices for tailings are shown in Table 4-3.

Table 4-3
Tailings: Best Management Practices

Waste	Best Management Practice
Pyritic or sulfidic wastes with ARD potential	Segregate pyrites from other gangue material and selectively discharge to saturated zone of tailings impoundments to reduce the potential for sulfuric acid formation after mine closure
Metals and cyanide	90% or more of metals and cyanide can be removed from discharge waters through the use of trace metal removal systems, cyanide destruction systems, precipitation of heavy metals using lime, oxidation of cyanide, ion exchange or filtration
Water	Whenever possible, water from tailings ponds should be decanted and recycled rather than discharged.
Water	Water may be recovered from the tailings slurry using thickeners for immediate reuse in the milling circuit
Solids	Tailings may be suitable for manufacture into saleable products, e.g., brick, tile, construction aggregate, etc.

There are several methods for disposing of tailings:

Subaqueous discharge produces lower in-situ densities than do subaerial methods, but this method inhibits the transfer of oxygen to tailings, which minimizes the potential for acid generation for tailings with acid rock drainage (ARD) potential.

Layered method (subaerial deposition) deposits tailings slurry in thin layers of uniform thickness (10 - 150 mm). The final configuration is a gently sloping mass of tailings, made from uniformly thin layers of high density with a resulting vertical permeability several orders of magnitude lower than its horizontal permeability. The advantage of this method is that tailings are well drained and fully consolidated upon mine decommissioning. Depending on needs for site preparation, the capital cost associated with this method can be high.

In the thickened tailings disposal method, the tailings slurry is thickened prior to its discharge from one or more spigotting points within the tailings disposal area. This method enables a greater storage capacity within a given disposal area than is allowed with conventional methods, as long as a high density can be obtained with thickening.

For tailings disposal behind a dam, the coarse tailings material is usually used to build the dam embankment. The tailings slurry can be discharged from a single point, through a series of spigots from a header, through spray bars, or through cyclones for the mechanical separation of tailings sands from the dam construction. Discharge of tailings through cyclones is preferred because of the greater control it provides regarding the size distribution of sand used for crest building.

Depending on the balance between rainfall, decanted water, evaporation, infiltration into the soil around the site, residual moisture and particle size distribution of tailings, and the mining methods used, some course tailings material may be used for backfill.

Only materials that do not generate acid should be used during construction of the tailings embankment.

4.2.2 Waste Rock and Overburden: Best Management Practices

When selecting a site for waste disposal, the topography of the site and the proximity to groundwater, streams, and rivers should be considered. Waste rock can be sloped to minimize uncontrolled runoff and to control the velocity of water that flows into containment ponds. The following are some practical steps for managing waste rock and overburden:

Site selection and geotechnical design are important since poorly design dumps and stockpiles can result in landslides and increased sediment load that may pollute nearby waters. The drainage of the pile must also be properly prepared to prevent mass wastings and landslides. Diversion ditches may need to be constructed above large dumps and stockpiles or those located on steep ground. Critical foundation materials should be removed and placed only during dry periods.

Dumps and stockpiles on hillsides or in ravines may need a properly constructed toe to key the pile into competent material. The toe may need a blanket drain to prevent the retention of water behind the toe.

Dumps and stockpiles should be graded to prevent water from ponding. The top of the dump should be sloped to direct runoff away from critical areas into a drainage system, or it should be crowned to disperse runoff around the perimeter.

Benches and terraces should be constructed at appropriate intervals with berms on the outer edge where possible to reduce water velocities and contain surface water for each bench.

When final grading and shaping is complete, the dump or stockpile should be capped and revegetated to minimize erosion.

4.3 ACID ROCK DRAINAGE (ARD)

The most significant potential for environmental impacts in the nonferrous metal mining industry is from acid rock drainage (ARD). ARD is derived from the oxidation of sulfide-containing minerals into sulfates and iron ions and by-products at rates faster than the neutralizing capacity of the rock can stabilize the pH above neutral. A potential consequence of ARD is the production of acid effluent containing elevated levels of dissolved metals, such as aluminum, manganese, lead, arsenic, copper, and zinc. ARD can affect underground and surface water, and it can leach from waste rock stockpiles and concentrator tailings deposits. ARD is aggravated in areas where mine operations intersect the water table and where the rocks contain iron sulfide or, less commonly, other sulfide minerals. ARD can occur while the mine is in operation or develop long after the closure of the mine.

4.3.1 Conditions Leading to Acid Rock Drainage

Some mines have waste rock that exhibits neutral pH; others may be weakly or strongly basic or acidic; only the acidic-tending wastes are problematic.

ARD formation involves a combination of geo-chemical and biological processes. In the commonly accepted model, three stages are considered in the generation of ARD. The first stage consists of the relatively slow chemical or biological oxidation of pyrite and other sulfide minerals near neutral pH. In stage two, in the presence of oxygen, ferrous iron is oxidized into ferric iron which precipitates as ferrous hydroxide and releases more hydrogen ion (acid). In stage three, bacteria can rapidly catalyze the process by oxidizing ferrous iron into ferric iron, increasing the overall rate of acid production by several orders of magnitude.

Both oxygen and water are required for ARD to occur. In fact, water plays an important role in removing oxidation products from the surface of sulfide minerals. Acid and sulfate salts may accumulate during dry periods and released at times of higher precipitation.

Carbonate materials such as calcite and dolomite are typical of the natural acid neutralizing components found in mine wastes. If present, these minerals can neutralize the acid produced by sulfide oxidation and prevent the establishment of low pH environments required by microorganisms. Where mine wastes have these conditions, the ARD process does not occur.

4.3.2 Characteristics of ARD Water

The upper limits of concentration ranges of pollutants in raw mine waters from lead and zinc mines with acidic conditions are given in Table 4-4. The table shows some of the characteristics of ARD such as low pH, high concentration of sulfate, iron, and base and trace metals. These figures highlight the importance of minimizing the occurrence of ARD and ensure that, where it does occur, preventive steps are taken.

Table 4-4
Extreme Characteristics of Acid Mine Drainage at a Lead and Zinc Mine

Constituent	Concentration (mg/l)	Constituent	Concentration (mg/l)
pH (in pH scale)	2.2	Cadmium	22.5
Sulfate	63,000	Magnesium	1,500
Total iron	16,250	Calcium	31.6
Zinc	14,560	Potassium	0.7
Nickel	4.8	Sodium	0.5
Copper	13.4	Chromium	0.3
Manganese	2,625	Chloride	38.0
Aluminum	347	Nitrate as NO_3	77.5
Lead	0.8		

Source: AEnvironmental Aspects of Selected Nonferrous Metals Ore Mining", UNEP Technical Report Series No 5.

4.3.3 Best Management Practices

Best management practices for the prevention and mitigation of acid rock drainage are summarized in Table 4-5.

Table 4-5
Acid Rock Drainage
Best Management Practices

Stage of Operation	Practice/Technique
Before, during and after mine operation	Establish an ARD prediction and monitoring program
During and after operation	Segregate acid-generating seepage and run off and non-acid generating seepage and runoff
During and after operation	Minimize the volume of water that is contacted with ARD conditions
During and after operation	Selectively place/cover acid generating material
During and after operation	Avoid or minimize exposure of sulfide minerals where possible
During and after operation	Avoid the use of sulfide bearing materials for the construction of dams, roads or other fill requirements
During and after operation	Place acid-producing wastes in areas where seepage can be controlled
During and after operation	Segregate clean and contaminated drainage to the maximum degree possible
During and after operation	Design and construct drainage control facilities to accepted criteria for surface run-off intensity and duration
Post-operation	Minimize the access of air to sulfides in underground closed mines by flooding and/or sealing the mine
Post-operation	Cap waste with clay, plastics, grout, asphalt, etc.
Post-operation	Surface application of top soil and revegetation
Post-operation	Combination of capping and top soil application

The primary strategy for managing ARD focuses on water control. A comprehensive water control strategy works both to limit contact between water and exposed mine rock and to control the flow of water that has been contaminated by mineral bearing rock. Successful prevention and control of water pollution, including ARD, requires knowledge of the quantities and quality of all waters which may be affected.

Treatment
The conventional approach to treating contaminated ground or surface water produced through acid rock drainage is an expensive, multi-step process that pumps ARD water to a treatment facility, neutralizes the contaminants in the water, and turns these neutralized wastes into sludge for disposal. The first step, equalization, involves pumping ARD water into a holding basin where a steady, equalized flow of water is then pumped out of the holding basin into a treatment plant for neutralization. The next step, aeration, involves moving the treated water to another basin where it is exposed to air. The metals precipitate typically as hydroxides, forming a gelatinous sludge which settles at the bottom for removal or disposal.

Management
Though contaminated waters resulting from ARD can be readily treated as described above, it is preferable to reduce the volume and improve the quality of contaminated waters. The physical control is important to the prevention and mitigation of ARD.

Any ARD water flow should be intercepted and diverted to an appropriate place for management.

All techniques attempting to control one or more of the basic elements of acid generation (oxygen, water, bacteria, and sulfide minerals) should be considered.

In underground mines, the main opportunity for minimizing water use is to seal and grout old boreholes and to reduce water penetration through shaft linings.

Water control in surface mining operations depends on site topography. In the case of surface mining and mine sites, runoff waters should be diverted by a ditch whenever possible.

Runoff waters from the processing site should be collected for treatment where required.

Runoff waters from the area surrounding the tailings ponds should be diverted to keep acid-generating seepage segregated from seepage that is not acid-generating.

Groundwater
Under some conditions, it is possible to minimize the recharge of groundwater and the direction of the groundwater flow in the vicinity of the mine in such a way that the production of ARD can be eliminated. BMP=s are also available to prevent ARD at closure. Minimizing the access of air to sulfides in underground closed mines can be achieved by flooding and/or sealing the mine. Other acid drainage control techniques can also be applied to waste and tailings disposal including capping or covering waste and applying top soil. In addition, preventative techniques

that are currently under study, such as covering waste with lime, limestone, or using bactericides to kill bacteria responsible for ARD.

4.4 AIR EMISSIONS CONTROL

Dust control may be one of the most critical elements of concern at mines. Crystalline free silica can cause chronic respiratory illness in workers exposed to excess concentrations. Lead, arsenic, cadmium, and other minerals typically found at mines may also be of concern.

Dust is usually generated from active surface mining excavations and waste rock piles. Mining equipment associated with open pit mining produces carbon monoxide, oxides of nitrogen, and sulfur from blasting and drilling operations (e.g., exhaust fumes). At active mining operations, water sprays are adequate for dust control at point and non-point sources. For tailings dams, water or chemical fixatives can be used for temporary dust control. When operations at mine facilities have been temporarily suspended or abandoned, dust emission becomes a more significant problem due to the fine material that tailings dams contain, which dry quickly on the surface.

Exhaust fumes from diesel engines and blasting agents can be serious hazards at underground mines. These exhausts produce carbon monoxide and nitrogen oxide gas, which collect in underground areas. Ventilation and monitoring of gas levels are critical to reduce the potential harm that these fumes may cause workers.

Table 4-6 lists potential sources of air emissions found at nonferrous metal mine sites.

Table 4-6
Potential Sources of Air Emissions

Point Sources	Nonpoint Sources
Ore and waste loading points	Waste dumps
Ore chutes in haulage systems	Ore stock piles
Screens in crushing plants	Haulroads
Exhaust from scrubbers	Tailings disposal areas
Dryer exhaust stack	

The most effective way to control dust emissions is to prevent dust formation at the source by controlling moisture levels in the handled product. Revegetation or rock capping are usually the most effective ways to prevent dust emissions from abandoned tailings ponds.

Haul roads are an intermittent source of dust that results from truck spillage and abrasion of the road base. A common approach to dust prevention is to spray water on the roads by means of tanker vehicles. Proper road compaction and grading also minimizes dust. Other sources of dust are open top trucks and railroad cars used to transport fine ground concentrates or other mining products. Covers, water sprays, and chemical stabilizers can be used for long haul vehicles.

Concentrates are another potential dust source. Concentrates produced in a mill are filtered. Filtration reduces concentrate moisture and thereby can increase the potential for dust emissions. An 8-10% moisture content is considered optimum to prevent generation of dust emissions from sulfide ore concentrates, while still controlling weight and minimizing the risk of liquefaction.

Water is used when needed to increase the surface moisture in areas where dust may be produced, such as crushers, screens, and ore chutes. Water sprays are far more effective in preventing dust production than in knocking down dust in the air. For a dust suppression system to be effective, it requires careful selection and positioning of the spraying equipment to optimize prewetting. Developing technologies that integrate water sprays and compressed air (sonic fogging nozzles) are particularly effective where water is limited and control requirements are critical.

4.5 LONG-TERM STABILIZATION: BEST MANAGEMENT PRACTICES

Revegetation of a minesite is practiced for three main reasons: to control erosion, to provide a productive land use, and to make the terrain more aesthetically appealing. Revegetation is probably the single best method of stabilization because it has a continuous and long-term effect. Revegetation prevents or reduces erosion by providing a soil cover that intercepts surface water runoff and prevents runoff from disrupting soil structure. The plant roots bind soil together and prevent water from carrying soil downhill. Vegetation also slows water runoff along the soil surface and enables more of the water to move into the soil for plant use. Local vegetation should be used to ensure proper growth and results.

4.5.1 Reclamation

Four general strategies are available for reclamation of surface mine areas. Some mines may use all four of these strategies:

< Post-mining reclamation: reclamation following depletion of all resources and closure of the mine

< Interim reclamation: reclamation to stabilize disturbed areas

< Continuous reclamation: reclamation as minerals are removed

< Segmental reclamation: reclamation following depletion of minerals in a sector of the mine

Post-mining reclamation is generally not preferred because it results in large areas being left unreclaimed for long periods. However, operational issues may necessitate post-mining reclamation. Interim revegetation is done seasonally to stabilize inactive mine areas or stockpiles to prevent erosion. This consists of grading and revegetation with grasses or legumes. Continuous reclamation typically involves transporting material from the new mining area to the reclamation area throughout the life of the mining operations.

In segmental reclamation, the mine site is divided into segments of fairly uniform characteristics and an order of mining and reclaiming is determined. Prior to mining, soil is stripped from the first segment and stockpiled to minimize handling. After the resources have been extracted from this segment the slopes are reshaped and stabilized. Soil is then stripped from the second segment and spread on the slopes of the first segment. Revegetation of the first segment is delayed until the area becomes inactive. Segmental reclamation works best where there are homogeneous deposits and where aggregate mining proceeds in increments. Table 4-7 lists disadvantages and advantages of each of the four types of reclamation.

Table 4-7
Advantages and Disadvantages of Different Reclamation Strategies

Type of Reclamation	Advantages	Disadvantages
Post-Mining	- Maximum resource recovery is more easily attainable in some instances - Reclaimed areas are not lost due to reactivation - Borrow areas can be mined for soil substrate and quickly revegetated to reduce the need for soil stockpiling	- Stockpiled soils may deteriorate during the life of the mine - Reclamation costs increase - Highest bond liability - No reclaimed segments are available as test plots for revegetation
Interim	- Soil viability is maintained - Fewer runoff control structures are needed because erosion-prone areas are vegetated - Air and water quality can be improved in the short term	- Areas may be redisturbed as plans change - Costs increase when material is moved more than once Duplicate costs for stabilizing then reclaiming the same area.
Concurrent (progressive)	- Soil and subsoil profile are more easily reproduced than in other types of reclamation - Materials are moved only once - Disturbance at any given time is minimized - Mined land can be reclaimed earlier for post-mining land uses - Low bond liability	- Generally not feasible in quarries or deep gravel deposits - Typically does not work if the water table is within the excavation.
Segmental	- Topsoil for most segments is handled only once and is not stored, reducing reclamation costs and preserving soil quality - Final slope angles and shapes can be established during excavation - Clay and silt needed for revegetation are less likely to be washed away - Restoration of chemical, physical, and biological processes is less expensive when reclamation is started as soon as possible - Minimized bonding liability	- Thin soils may render this technique impractical - It is impractical for those operations that must blend different sand and gravel sizes from various parts of the mine site in order to achieve product specifications - Poorly planned segmental reclamation may result in disturbing more land per unit of mineral produced

4.5.2 Site Preparation

Site preparation for reclamation should begin even before the ground is disturbed. Establishing setbacks prepares for reclamation but is also the best way to protect adjacent land and water during mining. Reclamation setbacks or buffers consist of preserved land along the margins of surface mines that will provide the material needed to accomplish restoration. Permanent setbacks or buffers consist of land that is set aside to remain undisturbed during mining to provide habitat or visual and noise screening. Setbacks should also be used to protect streams and flood plains, as these are particularly prone to damage from mining operations. Table 4-8 summarizes BMP=s for reclamation site preparation.

Table 4-8
Reclamation Site Preparation
Best Management Practices

Structure	Practice
Contours	Build the slope to approximate final contours to reduce reclamation costs by eliminating some of the earthwork necessary for final reclamation
Construction-limit or disturbance -limit markers	Mark permit boundaries, setbacks, buffers, segments, and storage and processing areas using flags fences or monuments.
Maintain disturbance-limit markers	Markers should be maintained until reclamation is complete
Setbacks, buffers, and storage areas	Setbacks, buffers, and storage areas should remain undisturbed until reclamation. Keep equipment and stockpiles materials out of these areas
Permanent setbacks	Establish permanent setbacks to provide habitat for vegetation surrounding the mining site
Reclamation setback	Establish reclamation setbacks to provide sufficient material to accomplish reclamation
Topsoil and overburden conservation	Prior to mining a segment, available topsoil, and overburden should be stockpiled in separate, stable storage areas for later use in reclamation or immediately moved to reclaim adjacent depleted segments.
Topsoil storage areas	Topsoil stockpiles needed for reclamation should be marked, stabilized, and isolated from other mine wastes

4.5.3 Revegetation

Revegetation consists of the following basic steps:

< regrading and shaping of mine spoils
< soil sampling and analysis
< seedbed preparation
< planting
< mulching
< monitoring
< maintenance

Regrading and Leveling
Before revegetation can be implemented, minesoils and overburdens must be regraded or contoured to promote the establishment of the vegetative cover. Local soil conditions, hydrology, vegetative type and other factors will affect the amount of regrading and leveling needed.

Soil Sampling and Analysis
Soil quality is one of the most important determinants of successful reclamation, as vegetation cannot be established if the soil is too poor. Soil testing and analysis is conducted to determine the kinds and amounts of nutrients in a soil. ATopsoil≅ generally refers to the most fertile portion of soil and can be identified by its dark color and high organic content. Subsoils contain fewer nutrients, but can absorb moisture and nutrients when they are abundant in clay. Where the topsoil is poorly developed, topsoil and subsoil can be mixed to produce a growth medium. This growth medium should be removed and retained for reclamation. Even a few inches of nutrient rich topsoil or growth medium over a nutrient poor soil can have a dramatic effect on the success of subsequent plant growth.

Soil testing and analysis has been used for many years to determine the kind and amounts of nutrients in a soil. Purchase of limestone and fertilizer should be delayed until samples of the mine soil have been taken, sent to the testing laboratory, and the test results received. Information that will be needed includes soil paste, pH level, amount of lime needed, and the amounts and types of nutrients that should be added to the minesoil.

Seedbed Preparation
Preparation of the seedbed is also critical to the success of mineland reclamation. A seedbed should be prepared in such a way that the soil will provide sufficient moisture, acceptable temperatures, optimum fertility, and proper tilth for successful germination and plant establishment. The purpose of tillage is to establish and promote a vegetative crop of some type.

In land reclamation, the crop is usually a forage crop or tree crop. A seedbed should be loose enough to be penetrable by air and the delicate roots of new seedlings, but firm enough that the soil will have micropores to transmit water to germinate seed. To counteract excessive compaction, seedbed preparation typically includes pipping haulroads, waste dump tops, and plant site areas.

Planting

Whatever the equipment or method used for planting, certain environmental factors must be taken into account in order to obtain satisfactory seed germination. Seeds must have adequate supplies of moisture and oxygen and a definite temperature range, as well as light to germinate. Planting methods can include broadcast seeding, aerial broadcast, drillseeding, or hydroseeding.

Mulching

Mulches applied to newly seeded minesoils will help to control soil erosion, reduce the loss of moisture from the soil surface, modify soil temperatures, prevent soil crusting, increase the amount of water stored in the soil, reduce animal predation, and hold the newly planted seeds in place. The three most common materials used for mulching in reclamation are straw, hay, and wood cellulose fiber. About 1-2 tons of mulch per acre is considered ideal, depending on climatic conditions.

4.6 MINE CLOSURE: BEST MANAGEMENT PRACTICES

The presence or absence of acid-producing characteristics is an important determinant of the measures that should be undertaken when a mine is closed. At mines that do not produce acids, reclamation measures may be sufficient to eliminate the need for long-term wastewater treatment. At acid-producing sites, contaminated drainage may occur that will need long-term treatment if the drainage cannot be effectively controlled.

The closure program should also include plans and mechanisms for continued monitoring of the site and the environmental impacts to ascertain the effectiveness of the reclamation and rehabilitation measures over time. Contingency plans should be developed for situations in which it is discovered after closure that environmental impacts have not been adequately mitigated.

There are three main post-closure concerns: drainage control, abandoned underground workings, and stability of stockpiles and impoundments.

4.6.1 Drainage Control

Drainage water may come from waste stockpiles and/or tailings disposal facilities. At mines that do not produce acid, mine water usually meets discharge requirements if subjected to conventional surface erosion and runoff control. The surfaces of stockpiles and tailings impoundments need to be treated only to the extent that surface erosion by water is prevented.

At ARD sites, the primary objective of post-operational measures is to reduce the volume and strength of acid drainage to a level where passive techniques will be sufficient to treat the residual drainage. In some cases this objective is not achievable and long-term treatment must be undertaken. Methods for minimizing the cost associated with ARD control are given in Table 4-5 of this chapter.

4.6.2 Abandoned Workings

For safety reasons, all access to underground workings must be controlled. When stabilizing an abandoned mine site, it may be difficult to locate access to ancient workings. Shafts often were sealed with wooden bulkheads topped with earth fill, or more recently, with concrete caps.

Current BMP is to completely fill the shaft with inert material, allowing some fill shrinkup to occur. Adits should be plugged with masonry block or monolithic concrete. Long-term subsidence should be evaluated to determine if surface deformation could result in damage to buildings, and subsidence control may be required. Some closed mines have been converted for use as high-security storage facilities, warehousing sites, and even as an environment for mushroom cultivation. Wine storage is probably the best-known use of abandoned underground mines.

Backfilling of open pit mines is often not economically feasible. Where this cannot be done, best management practices include installing security fencing and signs, berming access points, and treating high walls to stabilize against excessive rockfall.

4.6.3 Stockpiles and Impoundments

In areas where acid rock drainage does not prevail, measures should be taken during the post-operational phase to monitor the geotechnical stability of stockpiles and/or impoundments and to install stabilization controls, including soil and vegetation.

CHAPTER 5
EQUIPMENT MAINTENANCE AND HOUSEKEEPING: BEST MANAGEMENT PRACTICES

One of the major waste streams generated by the mining industry comes from heavy equipment use and maintenance. This chapter describes the main concerns and best management practices for the following waste categories:

< Wastewater from parts washers and from washing shop floors and vehicles.

< Hazardous waste: solvents from equipment and parts cleaning; lubrication greases from vehicles, shovels, draglines, etc.; spent vehicle fluids and accessories; and paints.

< Solid waste: rejected metal parts, old tires, cable, broken hoses and belts, empty containers, etc.

The main wastes produced by mining equipment maintenance and housekeeping operations and the best management practices for handling them are summarized in Table 5-1.

5.1 WASTEWATER

Waste Streams

Wastewater in maintenance operations comes from washing vehicles prior to maintenance, from washing shop floors, and from parts washers that use water-based solutions.

The vehicle-washing waste stream consists of hot water, detergents, grease, oil, and solids, especially road dirt. Floors are washed with cold water and usually a non-hazardous high pH liquid cleaner. Parts washers use water, detergent (usually a biodegradable type), and sometimes a surfactant.

Improvement Options

Vehicles should be washed prior to maintenance in separate truck wash and concrete wash facilities. Concrete trucks should not wash out or discharge surplus concrete or washwater except at designated concrete washout areas located in the nearest fill area away from any washes

Table 5-1
Equipment Maintenance and Housekeeping: Best Management Practices

Waste Category	Waste Type	BMPs
Wastewater	Washing vehicles and shop floors, parts washers	Wastewater reuse for dust suppression Using floor sweeping instead of washing Collecting wastewater vs discharge to oil/water separator.
Hazardous Waste	Solvents from vehicle parts cleaning, general purpose cleaning	Using non-hazardous substitute products Product reuse through fitting parts cleaners with recycling pumps and filters Using industrial parts washers instead of cleaners Wastewater collection
	Lubrication greases: open gear compounds, extreme pressure (EP) greases, wire rope lubricants, cam and slide lubricants	Substituting tetrachloroethylene additives in open gear compounds with biodegradable additives Replacing lead in EP greases with antimony, bismuth, boron, and other products Energy recovery
	Spent vehicle fluids and accessories: used oil, filters, batteries	For used oil: off-site or on-site energy recovery or use as a crude lubricant Replacing terne plated filters (containing lead, tin) with non-terne plated filters Recycling of batteries
	Paints from touch-up of trucks and mining equipment, parts coating, and facility maintenance	Full consumption of paint and recycling of containers Recycling of solvents Switching to water-based paints and primers Switching from lacquer to enamel-based paints
Solid Waste	Scrap metal, vehicle tires, steel cable, cleaning rags, paper, etc.	Recycling of scrap metal and tires On-site landfilling

or streams. A concrete washout area is a shallow pit dug in the fill material around which is a protective berm created using the excavated material. Once pouring activities are complete and the discharged washwater and materials have been absorbed into the fill materials in the pit, the fill is regraded with the concrete materials permanently incorporated into the fill.

Water usage can be reduced by substituting waterless cleaning for shop floors. Portable containers can be used to catch fluids as they are drained from vehicles or drip from components under repair. Absorbents should be used to catch inadvertent fluid spills. Sweeping the floors instead of washing them will significantly reduce the wastewater volume.

Wastewater may be reused onsite for dust suppression after the principal waste components have been removed. Solids should be settled out in special traps. Used oil should be skimmed from the water surface, perhaps using an oil skimmer as part of the wastewater sump system. The skimmed oil can be burned onsite for heat recovery or transported offsite for fuel blending.

5.2 HAZARDOUS WASTE

5.2.1 Solvents

Waste Streams

A variety of solvents (or degreasers) are used in the vehicle maintenance program, from typical hazardous chlorinated solvents to non-hazardous solvents with a citric base. Parts cleaning generally accounts for the largest volume of solvents used in mining operations. A mine can generate 5-15 tons per year of hazardous waste from solvent parts cleaners. A parts cleaner is usually a sink-type device that dispenses solvent from a faucet and collects the spent solvent in a drum beneath the sink.

Solvents are also used to wipe down surfaces that have been exposed to grease and other lubricated fluids. A number of products are used for this, such as non-chlorinated petroleum naphtha, which contains ethyl benzene, xylene, and aromatic and mineral spirits.

Improvement Options

Product substitution is the best way to reduce the contribution that solvents make to the hazardous waste stream. Many non-hazardous substitute products exist. Unfortunately, some users have discovered that twice as much solvent is needed if a non-chlorinated solvent is being used. Another way to minimize the use of hazardous solvents is to do cleaning in stages. For example, a non-hazardous solvent can be used for basic cleaning and a chlorinated solvent only to remove the residue.

Industrial parts washers present a technological substitute for solvent cleaners, provided they are equipped with an oil-water separator, filters, and sludge collectors. Washers come in different sizes, with the large size capable of handling most parts typically cleaned during vehicle maintenance.

If parts cleaners are used, they should have filtering units that remove grease and solids and allow for solvents to be reused. Parts cleaners fitted with recycling pumps and filters can extend the useful life of solvents and reduce solvent waste generation by 50% or more. A system of filters keeps the solvent usable for a long time. The spent filters may be considered hazardous waste and need to be managed accordingly.

5.2.2 Lubrication Greases

Waste Streams

Greases present a waste disposal problem not only because of the hydrocarbon nature of the lubricants but also because the additives that distinguish one product from another are considered hazardous wastes. Two broad categories of lubricants are used in mining operations: grease lubricants for vehicles (e.g., haul trucks) and carrier-applied greases for shovels, draglines, and open bull gears.

Lubricating greases for vehicles are usually an insignificant waste stream: only small quantities of waste grease are discharged with wastewater when vehicles are washed prior to maintenance.

Some dragline operations use lubricants which can be classified into four somewhat overlapping categories:

< open gear compounds
< extreme pressure greases
< wire rope lubricants
< cam and slide lubricants.

Open gear compounds are commonly used on large open gear and pinion sets. They are asphaltic (heavy black oils with high viscosity) in nature and require a fast drying solvent, such as trichloroethylene (TCE) as a Acarrier≅ which makes the grease more pumpable. Some dragline operations use lubricants containing biodegradable solvents rather than hazardous solvents. These lubricants consist primarily of petroleum resins and oils, with minor constituents that include lubricating solids, additives, and biodegradable components. A large machine may use 2 tons or more of open gear compounds per year. Approximately 50% of open gear compounds are usually recovered for disposal as either hazardous or non-hazardous waste, depending on the constituents.

Extreme pressure (EP) greases are used in anti-friction bearings and higher speed applications. They consist of an oil base compound, a thickener system (often lithium or calcium soaps), and additives that are dominated by lead (up to 35% of the lubricant by weight). Annual use of EP lubricants is 1-1.5 tons per machine. Less than 5% of EP greases are typically recovered, usually during major cleaning and rebuild operations.

Both hazardous and non-hazardous wire rope lubricants are used in surface mining operations. They consist of petroleum hydrocarbons and EP additives. For the most part, these lubricants are dispersed throughout the length of the rope and cannot be recovered.

Cam and slide units may use non-hazardous open gear compounds with hazardous additives. A propel system known as Monigham cam uses a lubricant that contains from 5 to 25% chlorinated solvents as a diluent. Annual use of cam and slide lubricants ranges from 0.4 to over 3 tons per machine, with approximately 80% of this grease being recovered for disposal.

Improvement Options

At the present time, product substitution is a common way of reducing hazardous waste created by lubrication greases. Many mining companies have moved away from TCE additives in open gear compounds and substituted biodegradable additives. Once the switch is made to a non-hazardous grease, it may take several months to purge the system of the hazardous grease. During the purging process hazardous waste continues to be generated. Lead in EP lubricants is now commonly being replaced with antimony, bismuth, boron, and other products. In some cases, draglines and shovels can be retrofitted with lubricating systems that are less wasteful or do not require hazardous lubricants. When lubricants are disposed of, it is preferable to use them for energy production as boiler fuel rather than as a waste deposited in landfills.

5.2.3 Spent Vehicle Fluids and Accessories

Waste Streams

The heavy equipment used in hard rock mining produces large volumes of used oil and hydraulic and transmission fluids. The amount of oil depends on the type of vehicles used and may range from approximately 20,000 gallons to over 100,000 gallons each year for a typical mining operation. Engine coolants (commonly, antifreeze) are typically considered hazardous because they contain ethylene glycol and detectable concentrations of benzene, toluene, lead, zinc, arsenic, mercury, and copper which accumulate in the cooling system.

The main types of accessory waste are filters and batteries. Filters are utilized to remove particulates from the fuel, lubrication, or control systems of vehicles. To increase the life of many filters and to provide for corrosion resistance, some manufacturers plate filters with a lead and tin coating on the internal surface (terne plated filters). These constituents make terne plated filters hazardous waste.

In terms of weight, spent lead batteries can be one of the largest categories of hazardous waste associated with vehicle maintenance operations. Large mines may need to dispose of more than 300 batteries per year.

Improvement Options
Several options are available for the management and waste minimization of used oil. These options include:

< offsite energy recovery
< onsite energy recovery
< reusing/recycling.

Off-site energy recovery through fuel blending and supplemental fuel programs is a commonly used method of oil recycling in the U.S. mining industry. Another accepted management practice is to burn used oil on-site, in a used oil furnace. This reduces both disposal costs and heating costs. Some used oil burners offer both heating systems and hot water applications so that year round energy recovery can be accomplished. The capital costs of used oil burners are easily offset by the savings on used oil shipment costs and raw fuel costs.

It is also possible to utilize used oil as a wire rope lubricant. If the acidity of the used oil is above 7.0, it can be sprayed on wire ropes. Before being used, it must be carefully filtered to remove all particulates that could plug the lubrication system.

Most mining operations in the U.S. are discontinuing the purchase of terne plated filters and replacing them with non-terne plated filters. Terne plated filters can be recycled as scrap metal.

Hazardous waste resulting from the spillage of water-activated batteries can be eliminated through the use of sealed batteries that are not water-activated and/or gel-filled batteries. An advantage of sealed batteries is that the battery can be placed in any orientation within the equipment. This allows for greater flexibility in use. In addition, these batteries do not emit explosive or corrosive vapors.

5.2.4 Paints

Waste Streams
Paint is used for a variety of operations, including touch-up of trucks and mining equipment, parts coating, and facility maintenance. Some paints are considered hazardous due to heavy metals they may contain, including arsenic, lead, cadmium, chromium, and zinc. Certain types of paints may contain hazardous solvents.

Waste generated from painting operations include leftover paint, paint sludge, paint containers, spent solvents/thinners from paint removal and cleaning of painting equipment, and air emissions of volatile organic compounds (VOCs).

A wide variety of options are available for minimizing paint-related wastes:

< *Consume paint completely.* This applies to both paint cans and aerosol containers. Empty containers should be drained and depressurized properly before disposal. The best alternative is to recycle empty metal paint containers.

< *Recycle solvent.* Spent solvent can be recycled either on-site or off-site. Simple on-site recycling and reclamation can be accomplished by gravity separation. Distillation units can be installed for recycling solvents onsite.

< *Switch to water-based paints and primers.* Water-based products reduce VOC emissions and produce less hazardous waste due to the limited amount of solvent in the paints.

< *Switch from lacquer to enamel-based paints.* Lacquer paints may contain 70-90% of solvent by volume while enamels contain 55-75% of solvent by volume. The use of enamel-based paints can result in a significant reduction of VOC emissions.

5.3 SOLID WASTE

Waste Streams

Mines generate various types of scrap metal, including broken parts and cuttings from machine shops. Another source of solid waste are tires, both light vehicle tires and large tires from haul and shovel trucks. The draglines and shovels discard worn out steel cable that is used for hoisting, dragging, and releasing the digging bucket. Other types of solid waste include cleaning rags, wooden spools from dragline/shovel ropes, and paper.

Improvement Options

Scrap metal and tires should be recycled through off-site vendors. In the absence of such recycling capabilities, they can be landfilled. Steel ropes, rags, and paper can be landfilled on-site.

CHAPTER 6
MINERAL PROCESSING AND METAL REFINING

This chapter focuses on mineral processing and refining of nonferrous metals from ore concentrates. Primary nonferrous metal manufacturers include smelters and refiners.

The manufacturing process first separates the desired metal from all other metals and compounds with which it is found. Then the metal is concentrated and refined. Metals produced as byproducts or coproducts of primary metals are themselves considered primary metals. Nonferrous metals processing and refining is complex and the production process for a specific metal is dictated by the characteristics of the raw materials, the economics of the product recovery, and the process metallurgy and chemistry of the metals.

Two types of metal recovery technologies are generally applied to produce refined metals, pyrometallurgical and hydrometallurgical. Pyrometallurgical technologies use heat to separate desired metals, and include drying, calcining, roasting, sintering, retorting, and smelting. Hydrometallurgical technologies separate the desired metals from the undesirables using techniques that capitalize on differences between constituent solubilities and/or electrochemical properties while in aqueous solutions. Examples include leaching, chemical separation, electrolytic recovery, membrane separation, ion exchange and solvent extraction.

6.1 TYPICAL WASTES

6.1.1 Air Emissions

Metallurgical processing generates three major types of air emissions: sulfur dioxide, particulates, and constituents such as fluorides.

Sulfur dioxide is the primary pollutant generated by the smelting of copper, lead, and zinc ore concentrates. Roasters, reverberatory furnaces, converters, and sinter machines are potential sources. Emissions are characterized by heavy mass rates and relatively weak flue gas concentrations from reverberatory furnaces and uneven pulsating flows from converters. In addition, small concentrations of contaminants harmful to human health such as arsenic, bismuth,

cadmium and mercury are frequently found in smelter emissions. These factors make the collection of sulfur pollutants difficult and costly due to the size and specificity of the equipment needed. Control techniques involve conversion of the sulfur dioxide to sulfuric acid or elemental sulfur.

The high concentration of SO_2 gas produced by smelting operations can be used to produce either liquid SO_2, sulfuric acid, or elemental sulfur. However, because these operations are often performed in remote locations, the converted products may have limited local markets and transportation is hazardous/expensive. The preferred by-product in such cases may be elemental sulfur because it is easier to transport. At some operations, by-product sulfuric acid can be used to leach Aoxide≅-type copper ores.

Another common type of air emission from the processing of nonferrous metals consists of micron sized particulates. Control of these fine particles requires efficient collection equipment such as baghouses, electrostatic precipitators, and high pressure drop scrubbers.

Finally, smelters generate small concentrations of volatile constituents such as arsenic, lead, zinc and fluorides.

6.1.2 Wastewaters

Nonferrous metals manufacturing wastewaters can contain concentrations of toxic metals including antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. These are generally free from strong chelating agents, making removal easier. Metal pollutants are removed by chemical precipitation and sedimentation or filtration. Most of them may be removed by reacting with lime, sodium hydroxide, or sodium carbonate. For some, better removal rates can be achieved using sodium sulfide or ferrous sulfide to precipitate the pollutants as sulfide compounds with very low solubilities.

6.1.3 Solid Wastes

Concentrate smelting and refining are accomplished by a variety of processes which may include drying, calcining, roasting, sintering, or retorting followed by reduction to metal (in a furnace or electrolytically) and subsequent refining. Impurities are removed or driven off in the form of gases, fumes, particulate dusts, and/or slag, all of which must be collected and either recycled to the process or disposed of. Sulfur in the concentrates is usually volatilized as sulfur dioxide gas. Waste slurries and sludges may be generated in large quantities. Cadmium and lead are two metals common to many wastes generated in the nonferrous smelting industry. Other metals found in many waste streams include copper, zinc, silver, aluminum, and chromium.

Table 6-1 gives typical concentration ranges for metals in wastes from the nonferrous smelting and refining industry.

Table 6-1
Concentration Ranges for Metals in Wastes from the Primary Smelting and Refining of Metals (Φg/l)

Metal	Aluminum	Copper	Lead	Zinc
Arsenic	ND-260	<2.0-310,000	58-96	3.0-3,000
Cadmium	2.3 - 200	<5-9,600	690-2,700	350-44,000
Chromium	ND-2200	<10-73	9.1-30	<24-610
Copper	13-140	1,600-450,000	100-5,300	37-20,000
Lead	0.58-780	<20-170,000	7,900-24,000	280-18,000
Nickel	500-770	<20-1100	50-150	<50-4,300
Silver	ND-<250	20-480	ND-<20	<25-740
Zinc	ND-540	30-150,000	2,700-20,000	8,700-1.7×10^6

Source: Noyes, Robert, Pollution Prevention Technology Handbook, 1993 p. 303.

6.2 BEST MANAGEMENT PRACTICES

Waste loads from nonferrous metal processing requiring end-of-pipe treatment can be significantly reduced and in some cases eliminated using preventative approaches. When pollution control technology recovers a material that can be reused, both treatment and pollution control are involved. In other cases, more efficient processing reduces the cost and need for pollution control technology. In-plant measures that improve efficiency and reduce waste generation include recycling and recovery of waste streams, water conservation, automatic controls, good housekeeping practices, process modifications, and waste treatment.

Under the Toxics Release Inventory (TRI) in the U.S., data are collected on the nonferrous metal processing industry to help provide an understanding of the quantities of waste handled by the industry, the methods typically used to manage this waste, and recent trends in these methods.

In the United States, 30 percent of nonferrous metal production-related waste was either transferred off-site or released to the environment. Most of this waste is recycled off-site,

recovered for energy use, or treated off-site. About 13 percent is either released to the environment through direct discharge to air, land, water , and underground injection, or it is disposed off-site. About 70 percent of the industry=s TRI wastes were managed onsite through recycling, energy recovery, or treatment.

Table 6-2 summarizes best management practices in nonferrous metal processing and refining, listed by unit operation.

Table 6-2
Processing and Refining
Best Management Practices

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Casting	Recycle casting contact cooling water
Various unit operations	Recycle air pollution control scrubber liquor either within the scrubber or treat by sedimentation before returning to scrubber
Casting	Return casting contact cooling water to the casting process after the water passes through the cooling tower
Various unit operations	Reuse process water in a different unit operation
Various unit operations	Replace contact cooling water with non-contact cooling water when possible
Cast metal production	Consider air cooling as an alternative to contact cooling
Slag processing	Find alternate use for dry slag such as using in a concrete agglomerate or for road surfacing
Slag processing	Reprocess slag if metal content is high enough. Wet or dry milling with recovery by melting is one method.
Slag processing	Granulate slag and then mix with ore concentrate sintering feed to control metal content of feed
Various unit operations	Use baghouses or any ESP=s to capture and reuse particulate losses
Various unit operations	Use afterburner to treat combustible particles captured from air emissions control equipment
Casting	Convert to dry air pollution control equipment to eliminate water use
Inert gas or salt furnace fluxing	Use dry air pollution control methods
Furnaces and smelting operations	Use dry air pollution control methods such as sulfur fixation equipment which recover sulfur for conversion to another product

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Air emission control systems	Reduce the volume of scrubber water used for air pollution control by using sonic water sprays to minimize the volume or severity of air emissions
Ore processing	Use improved techniques during ore processing to prevent arsenic and other toxic contaminants from accompanying the metal concentrate to the furnace. Selective flotation reagents offer a possibility.
Smelting/roasting	Use the appropriate method for the specific metal. Hydrometallurgical processing generates less gaseous emissions than pyrometallurgical methods; it often generates sizable amounts of liquid and solid wastes, and is usually more energy intensive.
Furnaces and smelting operations	Use newer furnaces and processes that are completely sealed from the working environment, making for less gaseous emissions and greater ease of sulfur recovery.

6.2.1 Recycle of Non-Process and Process Water

There are two main liquid waste streams in nonferrous metals processing facilities that are commonly recycled: casting contact cooling water and air pollution control scrubber liquor. The wastes for each can be recycled within a given process or combined with waste from other processes, treated, and then recycled to the process where it originated. For example, scrubber liquor may be recycled within the scrubber or treated by sedimentation and recycled back to the scrubber.

Recycling is the technical basis for many of the best practices promulgated by the U.S. Environmental Protection Agency (USEPA). According to the USEPA, the best available technology that has been determined economically feasible for most types of nonferrous metal processing will allow for a 90% recycle of wet air pollution control and contact cooling water. For some waste streams the number is even higher. In these systems, water can be used in wet air systems to capture particulate matter or fumes evolved during manufacturing.

An example of a BMP for recycling process water is the return of casting contact cooling water to the casting process after the water passes through a cooling tower. Two types of recycle are possible, either recycle with a bleed stream (blowdown), or total recycle. If concentrations of dissolved solids, such as sulfates and chlorides, are too high, then the waste stream may crystallize, forming scale as the solubility limits are exceeded. A bleed stream may be used to prevent such a build-up. Ten percent bleed is a common value used for a variety of processes. The recycling of process water is currently practiced where it is cost effective, where water is in short supply, or where the practice is required by the government permitting authorities.

The equipment needed for a recycling system is specific to the process for which it will be used. At a minimum, components generally include pumps and piping plus any equipment used for recovery/treatment prior to recycling. Chemicals may also be necessary to control scale build-up, slime, and corrosion problems, especially with recycled cooling water. Various chemical additives are used in cooling water systems to control scale, slime, and corrosion. The chemical additives needed depend on the character of the make-up water. All additives have definite limitations and cannot eliminate the need for blowdown. Care should be taken in selecting additives, as some water additives are extremely toxic.

Recycling through cooling towers is a common practice in the mining industry. Contact cooling water is recycled through a cooling tower with a blowdown discharge. The water and air flows are directed in such a way as to provide maximum heat transfer. The heat is transferred to the air primarily by evaporation while the remainder is removed by sensible heat transfer.

Recycling offers economic as well as environmental advantages. Water consumption is reduced and wastewater handling facilities (pumps, pipes, clarifiers, etc) can be sized for smaller flows. By concentrating the pollutants in a much smaller volume (the bleed stream), greater removal efficiencies can be attained by any applied treatment technologies. Recycling may require some treatment such as sedimentation or cooling of water before it is reused.

Experience in the U.S. shows that a recycle rate near 90% is feasible. Of 61 aluminum smelting and forming plants in the U.S., 29 recycle more than 90% of the direct chill casting cooling water. Two of the 5 aluminum smelters in the U.S. that engage in continuous rod casting are able to recycle 90% or more of their contact cooling water. Ninety percent of scrubber water is recycled by half of the 8 primary aluminum plants in the U.S. that use wet air pollution control on anode bake ovens, by 5 of the 11 plants that use wet scrubbers on potlines, and by 3 of the 8 plants that use wet scrubbers for pot runs.

Elsewhere in the U.S. metals industry the experience is similar. Five of 10 primary electrolytic copper plants currently recycle 90% or more of their casting contact cooling water. Ninety percent or more of the scrubber water is recycled by 2 of the 3 primary zinc plants with leaching scrubbers, by 2 of the 5 primary tungsten plants with scrubbers on reduction furnaces, and by 6 of the 7 secondary silver plants with furnace scrubbers.

6.2.2 Reuse of Process Water

Reuse of process water is the practice of recirculating water used in one production process for subsequent use in a different production process. This may consist of using a relatively clean wastewater for another application, or using a relatively dirty wastewater for an application where water quality does not hinder its reuse. The advantages of reusing process water resemble those of recycling. Less waste is generated and treatment facilities can be sized for smaller flows. Also, in areas where water shortages occur, reuse is an effective means of conserving water. The equipment necessary for reuse of process waters varies depending on the specific application.

Reuse applications in the nonferrous metals manufacturing sector vary. For example, bauxite refineries commonly reuse water from red mud impoundments in digestion operations. A primary aluminum plant reuses waste water from casting for air scrubbing. A lead smelter uses wastewater from air scrubbing for slag granulation, where all the water is evaporated. A primary copper refinery reuses precipitated spent electrolyte, known as Ablack acid,≅ in leaching operations that are part of an ore processing plant.

6.2.3 Reduction in Use of Process Water

Reduction of process water use is accomplished by decreasing the amount of process water per unit operation used as an influent to a production process or unit operation. In some cases, non-contact cooling water can be used to replace contact cooling water. Using non-contact heat exchangers eliminates the concentration of dissolved solids that occurs by evaporation and also minimizes scaling problems. One U.S. copper refinery is currently using this method to achieve zero discharge.

6.2.4 Air Cooling of Cast Metal Products

Conversion to dry air pollution control equipment is another way to eliminate water use in some cases. Air cooling, for some operations, is an alternative to contact cooling water when tonnages being processed are low. However, maintenance costs for air cooling are generally higher than for contact cooling because of the longer conveyor, the added heat load on equipment and lubricants, and the need for added air blowers.

6.2.5 Dry Slag Processing and Granulation

Slag is a solid waste from metallurgical processes that must be disposed of or reprocessed. Slag can be prepared for disposal by granulation or slag dumping. In slag granulation, a high-velocity water jet is used to produce finely divided and evenly sized particulate solids, which can be used as concrete agglomerate or for road surfacing. Slag can also be dumped in a location where it ultimately solidifies.

Slag can be reprocessed if the metal content is high enough to be economically recovered. Wet or dry milling, and recovery of metal by melting can be used, but ultimately the reprocessed slag will need disposal. Although dumping the slag eliminates the wastewater generated during slag granulation, the large volumes of dust that are produced during subsequent crushing operations may necessitate use of dust control systems. Four of the 11 primary lead smelters in the U.S. currently granulate slag prior to disposal. One of these plants mixes the granulated slag in with ore concentrate feed to sintering. This serves to control the lead content of the feed.

6.2.6 Dry Air Pollution Prevention and Control

Process equipment modification can be used to reduce the amount of waste generated. Many copper, lead, and zinc refiners have installed sulfur fixation equipment. This equipment not only captures the sulfur before it enters the atmosphere, but processes it so that a marketable sulfuric acid is produced. Another example is the use of pre-baked anodes in primary aluminum refining. When a prebaked anode is used, the electrolytic cell, or pot, can be closed, thereby increasing the efficiency of the collection of the fluoride emissions. In addition, new carbon liners have been developed which significantly increase the life of the aluminum reduction cell. This has resulted in large reductions in the amount of spent potliner material generated by the aluminum industry.

Equipment for dry control of air emissions and particulate removal include cyclones, dry electrostatic precipitators, fabric filters, and afterburners. Afterburners are used for air emissions consisting mostly of combustible particles. Plants in the aluminum, zinc, lead, copper, silver, and gold industries in the U.S. are using dry air pollution control devices on furnaces and smelting operations.

There is an incentive for nonferrous metal manufacturing processors to limit the volume or severity of air emissions, since this reduces the volume of scrubber water used for air pollution control. For example, new or replacement furnaces can be designed to minimize emission volumes.

Experience in the U.S. has shown that using a dry air pollution control device can result in particulate removal efficiencies of greater than 99% by weight for fabric filters, electrostatic precipitators, and afterburners, and up to 95% for cyclones. Selecting a dry air pollution control

device, when there is a choice between a wet and a dry air pollution control device, can serve as a waste prevention measure in and of itself, in that there is no liquid waste created that must be treated. The use of dry air pollution control devices would allow the elimination of waste streams with high pollution potentials.

Selecting proper air pollution control equipment can be complex and sometimes a wet system is necessary. The important difference between wet and dry devices is that wet devices control gaseous pollutants as well as particulates. Wet devices are usually chosen over dry devices when any of the following factors are found: (1) the particle size is under 20 microns, (2) flammable particles or gases are to be treated at minimal combustion risk, (3) both vapors and particles are to be removed from the carrier medium, (4) the gases are corrosive, (5) the gases are hot.

6.2.7 Good Housekeeping

Good housekeeping and proper equipment maintenance are necessary factors in reducing wastewater loads to treatment systems. Control of accidental spills of oils, process chemicals, and wastewater from washdown and filter cleaning or removal can aid in maintaining the segregation of wastewater streams. Curbed areas should be used to contain or control these wastes.

Leaks in pump casings, process piping, etc., should be minimized to maintain efficient water use. One particular type of leakage which may cause a water pollution problem is the contamination of non-contact cooling water by hydraulic oils, especially if this type of water is discharged without treatment. A conscientiously applied program of water use reduction can be a very effective method of curtailing unnecessary wastewater flows. Reusing washdown water and avoiding unattended running hoses can also significantly reduce water use.

6.2.8 Technologies under Development

Along with hydrometallurgical processes for metals recovery from ores, several new pyrometallurgical processes are now in various stages of development around the world. One advantage offered by some of these is the elimination of metallurgical coke use, a major source of environmental problems. Other advantages include better containment and increased concentration of gaseous and particulate wastes, rendering subsequent treatment and recovery much easier and more efficient. Other developments include the treatment of wastes to recover arsenic and other metals formerly discarded because of lack of markets or lack of economic/ environmental incentive.

A major concern common to smelting of several kinds of metals is the concentration of arsenic oxide in the off dusts produced during processing. Recovery of other metals from the dust is

difficult. Using improved techniques during ore processing could prevent the arsenic from accompanying the metal ore to the furnace. This would carry with it two benefits. First, a major environmental contaminant would be prevented. Second, this would allow for greater reuse of metal still in the dust. Advanced flotation processes are being tested that would allow for the separation of arsenopyrites from sulfide ore concentrates, thereby removing the arsenic compounds before they reach the smelters.

The use of hydrometallurgical processing is increasing due to improvements in solvent-extraction technology and the need to recover metals from ores that are difficult to smelt or roast. Such processes also offer environmental benefits, generating less gaseous emissions and producing elemental sulfur.

While most of the copper produced in the U.S. is processed by smelting and electrorefining sulfide ores, better reagents and electrowinning techniques have lowered the cost of hydrometallurgical processes and encouraged the mining of oxide ores. Acid leaching and solvent extraction and electrowinning are now being used commercially for oxide copper ores in the U.S. and elsewhere.
In the case of sulfide ores, new chlorine leach technology is being developed that is environmentally beneficial and reduces energy costs.

Some primary metal smelting companies are currently recovering significant amounts of copper, zinc, and precious metals from metal bearing wastes. Many mining industry representatives report that this offers several advantages: 1) the metals are recovered and returned to commerce rather than being landfilled, thereby conserving resources; 2) the volume of incoming waste material is subsequently reduced; 3) the incoming hazardous waste material is transferred into a chemically inert slag.

6.3 ALUMINUM

6.3.1 Typical Wastes

Primary aluminum processing activities result in air emissions, process wastes, and other solid-phase wastes. Large amounts of particulates are generated during the calcining of hydrated aluminum oxide. Small amounts of particulates are emitted from the bauxite grinding and materials handling processes. Emissions from aluminum reduction processes are primarily gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, volatile organics, and sulfur dioxide from the reduction cells; and fluorides, vaporized organics and sulfur dioxide from the anode baking furnaces. Wastewaters generated from primary aluminum processing are produced during clarification and precipitation, though much of this water can be fed back into the process and reused.

Solid-phase wastes are generated at two stages in the primary aluminum process: red mud is produced during bauxite refining, and spent potliners are a byproduct of the reduction process.

Typical waste sources from primary aluminum smelters include:

< anode and cathode paste plant wet air pollution control
< anode bake plant wet air pollution control
< anode contact cooling and briquette quenching
< cathode reprocessing
< potline wet air pollution control
< potroom wet air pollution control
< direct chill casting
< continuous rod casting
< stationary casting or shot casting
< degassing wet air pollution control
< pot repair and soaking
< spent potliner leachate
< mud impoundment effluent
< casthouse dust
< cryolite recovery residue sludge
< spent potliners
< transfer and storage of materials
< reclaiming concentrates from storage bins

There are five basic steps in the production of alumina from bauxite ore: 1) crushing, screening and mixing with sodium hydroxide, 2) digestion and solubilization, 3) purification, 4) precipitation of purified aluminum hydroxide, and 5) calcination of the hydroxide filter cake.

Figure 6-1 shows a schematic diagram of the primary aluminum production process.

Figure 6-1
The Primary Aluminum Production Process

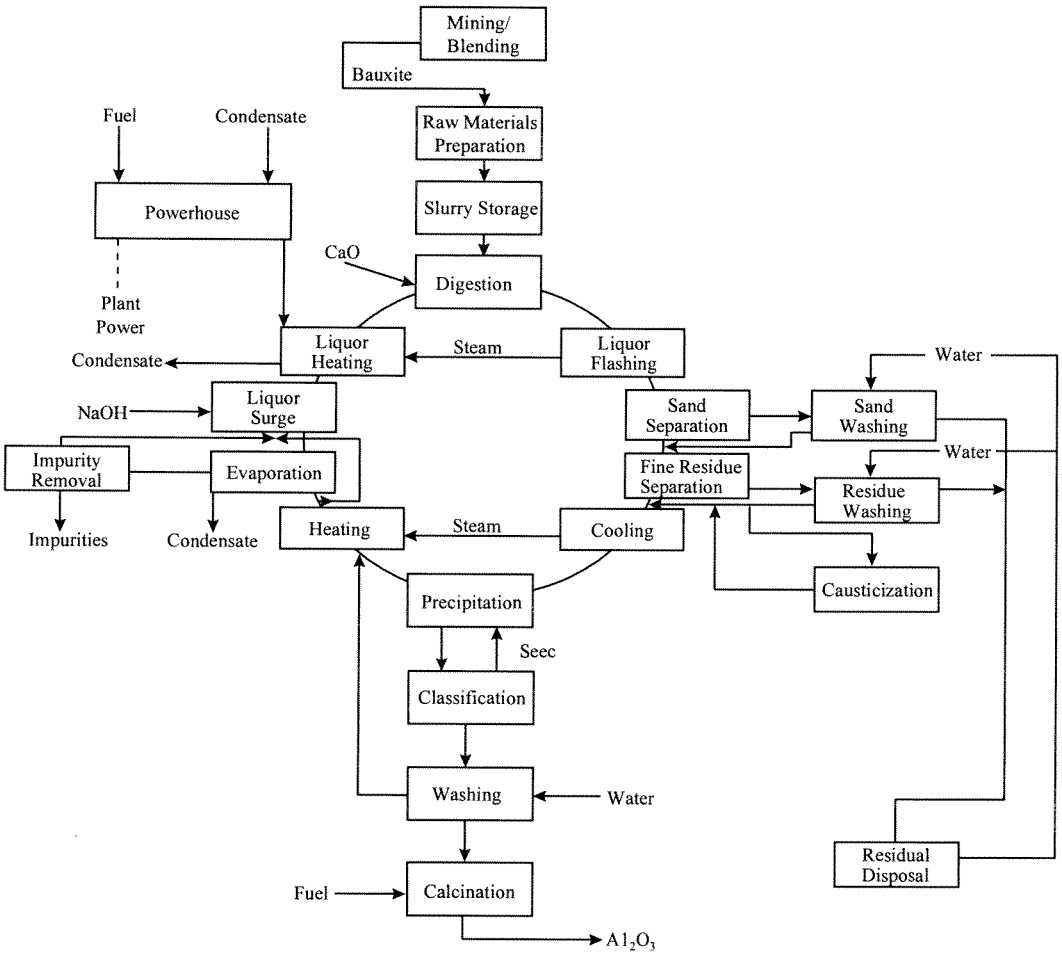


Table 6-3 shows process material inputs and waste outputs in primary aluminum processing.

Table 6-3
Process Material Inputs and Waste Outputs in Primary Aluminum Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Bauxite refining	Bauxite, sodium hydroxide	Particulates	N/A	Residue containing silicon, iron, titanium, calcium oxides, and caustic
Alumina clarification and precipitation	Alumina slurry, starch, water	N/A	Wastewater containing starch, sand, and caustic	N/A
Primary electrolytic aluminum smelting	Aluminum hydrate	Particulates an water vapor	N/A	N/A

6.3.2 Best Management Practices

Opportunities for waste minimization through raw material substitution are limited by the characteristics of the ores that are processed. Selection of source ores, improved ore processing techniques, or improvements in smelting technology, however, may lead to reduced waste volumes. Other source reduction opportunities may involve process modifications that increase the efficiency of metal recovery during the smelting operation. Table 6-4 summarizes best management practices in the processing and refining of aluminum.

Table 6-4
Best Management Practices in Aluminum Processing and Refining

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Smelting	Use continuous rod casting recycle of contact cooling water
Refining	Use pre-baked anodes to increase fluoride collection efficiency
Bake ovens	Use wet air pollution control on anode bake ovens
Potlines	Use wet scrubbers on potlines
Potlines	Recycle scrubber water from wet scrubbers used on potlines
Bauxite refining	Reuse water from red mud impoundments n digestion operations
Casting	Reuse wastewater for air scrubbing
Melting prior to casting	Restrict use of wet air pollution control to cases where chlorine gas is present in

UNIT OPERATION	BEST MANAGEMENT PRACTICE
	the off-gas, otherwise use dry control methods
Furnace fluxing	Replace furnace fluxing with in-line metal treatment units by treating aluminum in the transfer system between the furnace and casting units (this is accomplished by passing the metal through a region of very fine, mixed gas bubbles)
Degassing	Replace the chlorine rich degassing agent with a mixture of inert gases and a much lower proportion of chlorine (provides adequate degassing while permitting dry scrubbing)
Reduction of aluminum oxide	Use spent potliner as a direct fuel source
Calcining of hydrated aluminum oxide	Use wet scrubber to capture particulates

Air Emissions Prevention and Control

Emissions from aluminum reduction processes consist primarily of gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, volatile organics, and sulfur dioxide from the reduction cells, and fluorides, vaporized organics and sulfur dioxide from the smelting and baking furnaces.

A variety of control devices are used to reduce emissions from reduction cells and anode baking furnaces. One or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturis, and self induced sprays) as well as particulate control methods (electrostatic precipitators, multiple cyclones, and dry alumina scrubbers) have been applied to all three type of reduction cells and to anode baking furnaces. Alumina adsorption systems are also being used on all the cell types to control both gaseous and particulate fluorides. Bag houses are then used to collect residual fluorides entrained in the alumina and to recycle them to the reduction cells. Scrubber systems also remove a portion of the SO2 emissions. These emissions could be reduced by wet scrubbing or by reducing the quantity of sulfur in the anode coke and pitch (i.e., calcining the coke). In the hydrated aluminum oxide calcining, bauxite grinding and materials handling operations, various dry dust collection devices (centrifugal collectors, multiple cyclones, or electrostatic precipitators and/or wet scrubbers) are used.

Potliners

Aluminum metal is produced by the electrolytic reduction of aluminum oxide. The process takes place in a reduction cell, or pot, which consists of a strongly reinforced shell lined with heat insulation and a pre-baked carbon block and/or rammed monolithic carbon liner. Together these are termed the potshell. It is used to hold the molten aluminum and electrolyte and conduct the electricity out of the pot, thus serving as the cathode. A pot can normally operate for five years

and sometimes longer, but Afails≅ when iron is detected in the molten aluminum, when the cell voltage increases, or when the shell leaks molten metal or aluminum. When that occurs, the lining is removed and the steel shell is relined. The removed lining is called spent potliner. In the US, it is estimated that 100,000 tons of spent pot liner are generated annually.

New carbon liners have been developed which significantly increase the life of the aluminum reduction cell. This has resulted in large reductions in the amount of spent potliner material generated by the aluminum industry.

Spent pot liner also has a very high energy value, ranging from 8,000 to 9,000 BTU/lb. This makes it a valuable resource as a direct fuel. A coal fired electricity generator could replace 0.5% of its feed with spent potliner. In the US, however, environmental laws pertaining to hazardous waste prevent the reuse of spent potliner as a fuel. According to US law, all residue from the burning of hazardous waste is also considered a hazardous waste unless it is specifically delisted. This means that all ash from the combustion process would be deemed hazardous if spent potliner were added to the feed, making disposal of the ash too expensive. The same disincentive would likely not apply in Latin America. Thermal reclamation of spent pot liner could be a viable option.

Use of Pre-baked Anodes

Another best management practice is the use of pre-baked anodes in primary aluminum refining. When a prebaked anode is used, the electrolytic cell, or pot, can be closed, thereby increasing the efficiency of the collection of the fluoride emissions.

Capture of Particulates

In the preparation of refined alumina from bauxite, large amounts of particulates are generated during the calcining of hydrated aluminum oxide, but the economic value of this dust is such that extensive controls are usually employed to reduce emissions to relatively small quantities. This best management practice can be considered purely in terms of cost reduction potential. For moderate emission rates, a wet scrubber with a pressure drop of 1.5 to 2.5 kilopascals will capture 95% of emissions. With very low uncontrolled emission rates coming from high moisture conditions the percentage reduction is closer to 70%.

Limit Use of Wet Air Pollution Control Equipment

For aluminum smelters, melting prior to casting requires wet air pollution control only when chlorine gas is present in the off-gases. Dry air pollution control methods with inert gas or salt furnace fluxing offer a possible alternative to wet systems. Using only in line metal treatment units, it is possible to accomplish all the treatment objectives of removing hydrogen, non-metallic inclusions, and undesirable trace elements while still meeting tight quality requirements

without furnace fluxing. The molten aluminum is treated in the transfer system between the furnace and casting units by exposing the flow to a region of very fine, dense, mixed gas bubbles generated by a spinning rotor or nozzle. No process wastewater is generated in this operation.

Another similar alternate degassing method is to replace the chlorine rich degassing agent with a mixture of inert gases and a much lower proportion of chlorine. The technique provides adequate degassing while permitting dry scrubbing.

6.4 COPPER

6.4.1 Typical Wastes

Primary copper production operations include smelting, converting, fire refining in an anode furnace, and electrolytic refining. The products from each operation, respectively, are copper matte, blister copper, copper anodes, and refined copper. Three special mineral processing wastes are generated by copper processing operations:

< slag
< slag tailings
< sludge resulting from liming

Primary copper processing results in air emissions, process wastes, and other solid wastes. Particulate matter and sulfur dioxide are the principal air contaminants emitted by primary copper smelters. Copper and iron oxides are the primary constituent of the particulate matter, but other oxides such as arsenic, antimony, cadmium, lead, mercury and zinc may also be present with metallic sulfides and sulfuric acid mist.

Electrolytic refining produces wastewater that must be treated and discharged, reused, or disposed in some manner. Primary copper processing generates two solid-phase wastes: slag and blowdown slurry/sludge.

Typical sources of waste include:

< slag granulation
< casting contact cooling
< casting wet air pollution control
< acid plant blowdown
< acid plant thickener sludge
< process wastewater

< non-recyclable dusts
< scrubber blowdown

Figure 6-2 shows a schematic diagram of the primary copper production process.

Figure 6-2
The Primary Copper Production Process

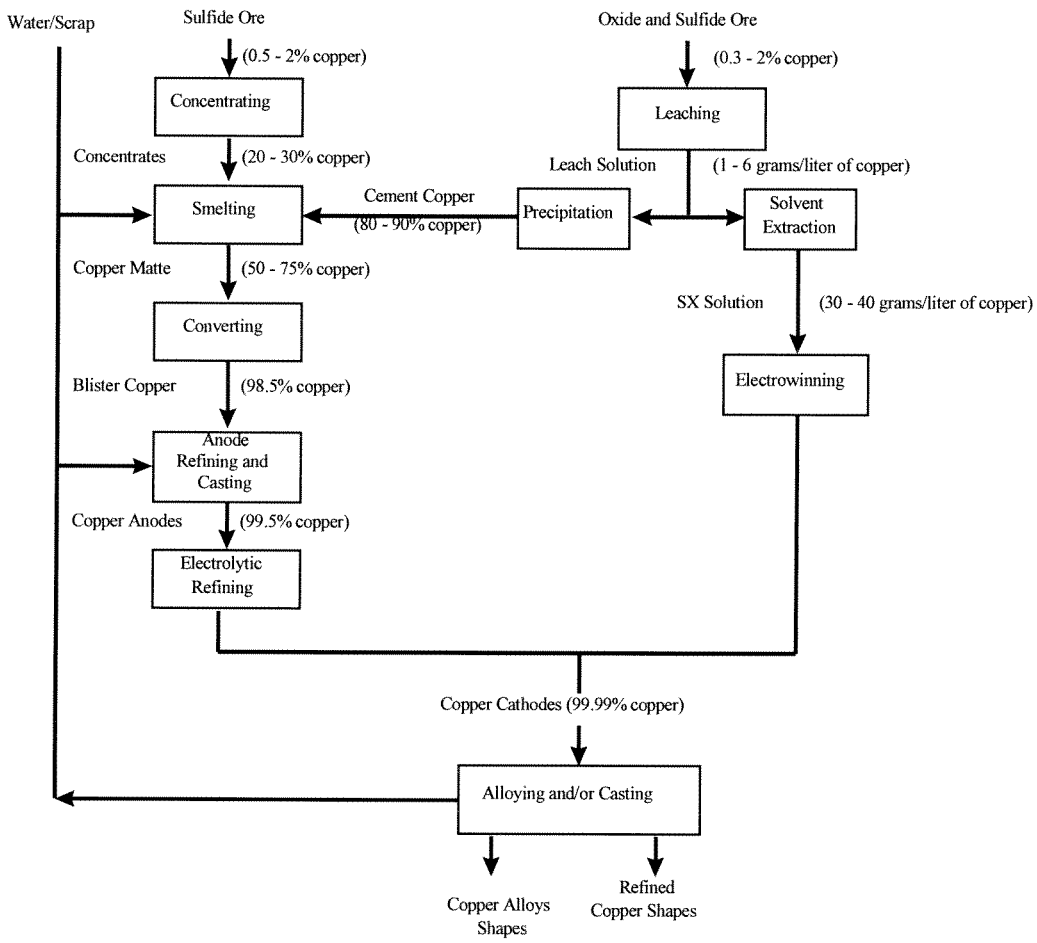


Table 6-5 shows process material inputs and waste outputs in primary copper processing.

Table 6-5
Process Material Inputs and Waste Outputs in Primary Copper Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Copper Concentration	Copper ore, water. Chemical reagents, flocculants	N/A	Flotation wastewater with dissolved solids	Tailings containing waste minerals such as quartz, oxides, silicates, and carbonate minerals
Copper Leaching	Copper ore, sulfuric acid, water	N/A	Uncontrolled leachate containing dissolved metal and other species	Dump or heap leach waste
Copper Smelting	Copper concentrate, siliceous, carbonate or oxide flux	Sulfur dioxide, particulate matter containing arsenic, antimony, cadmium, lead, mercury, and zinc	N/A	Acid plant blowdown slurry/sludge, slag (complex silicates, mainly silica, ferrous oxides and others, metallic oxides, minor amounts of copper, sulfur and other elements)
Copper Converting	Copper matte, scrap copper, siliceous flux	Sulfur dioxide, particulate matter containing arsenic, antimony, cadmium, lead, mercury, and zinc	N/A	Acid plant blowdown slurry/sludge, slag containing iron silicates and sulfides, copper
Anode Casting	Blister copper	Copper fume	Cooling water	N/A
Electrolytic Copper Refining	Anodes copper	Acid mist	Process wastewater	Slimes containing impurities such as gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulfur, and zinc

6.4.2 Best Management Practices

Opportunities for waste minimization through raw material substitution are limited by the characteristics of the ores that are processed. Selection of source ores, improved ore processing techniques, or improvements in smelting technology, however, may lead to reduced volumes of slag and furnace off-gases. Other source reduction opportunities may involve process modifications that increase the efficiency of metal recovery during the smelting operation. The following discussion describes opportunities for recycling copper smelter slag that are practiced in the US and miscellaneous potential waste minimization practices for all three special wastes generated in primary copper processing. Table 6-6 summarizes best management practices in the processing and refining of copper.

Table 6-6
Best Management Practices in Copper Processing and Refining

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Casting	Recycle casting contact cooling water
Electrolytic refining	Reuse precipitated spent electrolyte, Ablack acid≅, in leaching operations
Processing	Use hydrometallurgical processing where possible. Better reagents and electrowinning techniques have lowered cost significantly in recent years. Reduced emissions.
Various unit operations	Recover metals from metal bearing wastes
Ore processing	Improve ore processing efficiency to reduce slag volumes
Slag	Recycle copper slag to recover additional copper, particularly from smelting furnace slag
Converter slag	Recover copper from converter slag by leaching at high temperature with sulfuric acid
Slag	Recover iron and glass fiber from slag
Slag	Find alternate use for slag such as various kinds of construction material
Arbiter process	Recover and recycle ammonia from the Arbiter process by using a packed tower scrubber on emissions from leach reactors, mixers/settlers, and tanks

Recycling Copper Slag

Copper slag is typically recycled to recover additional copper. Some typical types of copper slag include: converter, anode, reverberatory furnace, electric furnace, flash furnace and continuous smelter (Noranda) slags. In almost all cases, anode and converter slag generated at primary copper processing facilities in the US are already recycled into the process. Similarly anode furnace slag is recycled to the smelting process. In addition, good opportunities exist for recycling slag for the remaining types of smelter slag. There are three primary methods of recycling copper smelter slag in the U.S. The choice of method depends on the type of smelting furnace in operation.

Reverbatory furnace slag may be recycled in a process of crushing, screening, and subsequent separation of the copper minerals in the slag by froth flotation. Flotation reagents are added to the flotation cell and selectively coat the copper mineral surfaces. These minerals attach themselves to air bubbles and are removed in a foam or froth which collects at the top of the cell. Other minerals do not attach to the bubbles and remain in the slurry, which is removed separately.

Slag from flash furnace and continuous (Noranda) smelter operations have a high copper content. To recover the copper a facility can use electric furnace slag treatment or slow cooling, crushing, and flotation. In an electric furnace, coke is used to reduce sulfates and metallic copper and reconstitute the copper as sulfide. The molten slag is cooled slowly, allowing copper mineral grains as large as possible to solidify, with copper suspended in a matrix of primarily iron silicate. The slag is crushed and then concentrated in the flotation concentrator. The resulting concentrate is then returned to the smelting process. The concentration of copper in the slag is the most important factor in determining the economics of recycling smelter slag.

Copper Recovery from Converter Slag

Researchers in India have found a way to recover copper from converter slag. The slag used had a magnetite content of approximately 8% and a FeO/SiO_2 ratio of about 1.2. It was leached at high temperatures with dilute sulfuric acid. Most of the copper and about 90% of the nickel and cobalt were extracted. Slags with higher magnetite content (15-20%) and a greater FeO/SiO_2 ratio (1.3) only yielded 40-60% recovery of the secondary metals; however, using slow cooling on this slag enhanced recovery of contained nickel and cobalt to 90%.

Iron Recovery and Glass Fiber Reduction from Slag

Researchers at the University of California in Los Angeles found that copper slag from ASARCO=s Hayden Arizona facility could be converted into glass fiber and that iron from the slag could be recovered. A mixture of 90% copper slag and 10% $CaCO_3$ was melted down in a Harper global electric heating furnace using graphite and coal powder as reductants. Reduction of the oxide through the ferrous state to the metallic state yielded iron from the slag. Glass was then cast and glass fibers were drawn from the melt.

Copper Slag Utilization

Copper slags have been used in a variety of ways. The application that has the potential to consume the largest quantities of copper slag is highway construction aggregate. One major copper mine in the Western U.S. is currently using crushed slag to construct a "drainage blanket" (a porous medium) to dewater the base of their new tailings pond dike. Other potential uses include:

< bituminous wearing surfaces (asphalt) and as a sel coat aggregate in highway construction
< Portland cement replacement material
< road cindering
< granules for roof shingles
< railroad ballast
< mineral wool insulation
< abrasive blasting grits for paint removal
< highway embankment material

Leaching

Dump and heap leaching techniques are growing in popularity as a way to extract metal from mine waste rock, low grade ores, and old concentrator tailings in which copper is found in minerals suited to extraction by leaching. These are discussed in detail in Chapter 3.

Air Emission Prevention and Control

The main contaminants generated by primary copper smelters are particulate matter and sulfur dioxide. These emissions stem directly from various processes such as in the liberation of SO_2 from copper concentrate during roasting, smelting, and converting, or in the volatilization of trace elements as oxide fumes. Fugitive emissions are generated by leaks from major equipment during material handling operations.

Single stage electrostatic precipitators (ESP) are widely used in the primary copper industry for the control of particulate emissions from roasters, smelting furnaces, and converters. If properly designed, these ESP=s can recover 99% or more of the condensed particulate matter present in gaseous effluents. Fabric filters can also be used for particulate spray collection. Flash smelting, using oxygen or oxygen-enriched air, can also reduce emitted gas volume, increase SO_2 concentration in furnace off-gas, and simplify treatment of off-gases for sulfuric acid production.

6.5 LEAD AND SILVER

6.5.1 Typical Wastes

The primary lead production process consists of four steps: sintering, smelting, drossing, and pyrometallurgical refining. Silver almost always accompanies lead in the ore and the two are processed together until separated at a point dictated by the type of ore and process used.

Primary lead processing activities usually result in air emissions, process wastes, and other solid-phase wastes. The primary air emissions from lead processing are substantial quantities of SO_2 and/or particulates. Particulate emissions from sinter machines range from 5 to 20 percent of the concentrated feed ore. Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron limestone-silicate slag, arsenic and other metallic compounds associated with lead ores. The blast furnace slag is composed primarily of iron, calcium, magnesium, and silicon oxides, and small amounts of lead, zinc, and sulfur, although many toxic metals may also be present in small amounts. Blast furnace slag is either recycled into the furnace or disposed of.

The smelting of primary lead produces a number of wastewater and slurries, including acid plant blowdown, slag granulation water, and plant washdown water.

Typical waste streams from primary lead and silver manufacturing include:

< sinter plant materials handling wet air pollution control
< blast furnace slag granulation
< blast furnace wet air pollution control
< zinc fuming wet air pollution control
< dross reverberatory slag granulation
< dross reverberatory furnace wet air pollution control
< hard lead refining slag granulation
< hard lead refining wet air pollution control
< facility washdown
< employee hand wash
< laundering of uniforms
< acid plant blowdown
< acid plant sludge
< baghouse dust
< spent furnace brick
< slag fines
< surface impoundment solids
< process wastewater

Figure 6-3 shows a schematic diagram of the primary lead production process.

Figure 6-3
The Primary Lead Production Process

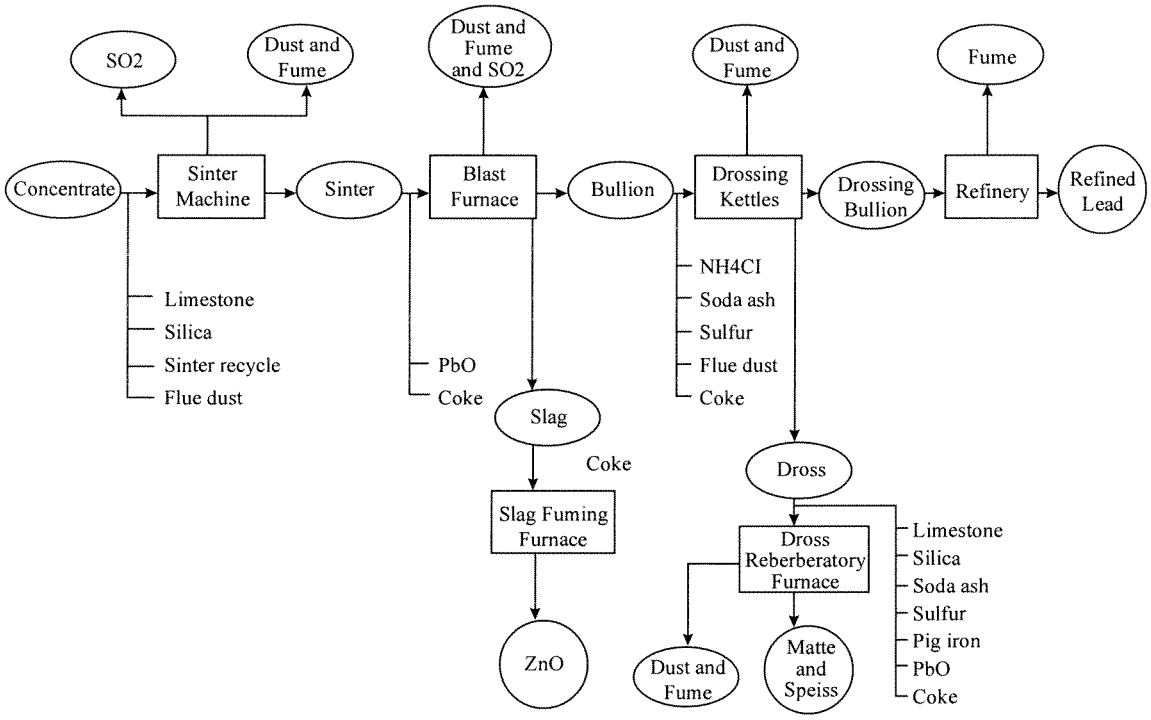


Table 6-7 shows process material inputs and waste outputs in primary lead processing.

Table 6-7
Process Material Inputs and Waste Outputs in Primary Lead Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Lead sintering	lead ore, iron carbonate and/or oxide, silica, limestone flux, coke, soda ash, pyrite, zinc sulfide, caustic, baghouse dust, air and water	Sulfur dioxide, particulate matter containing cadmium and lead	N/A	N/A
Lead smelting	Lead sinter, coke, limestone, air	Sulfur dioxide, particulate matter containing cadmium and lead	Plant washdown wastewater, slag granulation water	Slag containing impurities such as zinc, iron, silica, and lime
Lead drossing	Lead bullion, soda ash, sulfur, baghouse dust, coke/coal, air	N/A	N/A	Dross or slag containing such impurities as copper, sulfur, antimony, and arsenic
Lead refining	Lead, copper matte, scrap copper, siliceous flux	N/A	N/A	N/A

6.5.2 Best Management Practices

Opportunities for waste minimization through raw material substitution are limited by the characteristics of the ores that are processed. Selection of source ores and improved ore processing techniques, however, may lead to reduced slag volume in some cases. Other source reduction opportunities may involve process modifications that increase the efficiency of metal recovery during the smelting operation. The most prominent waste minimization practices currently employed in the primary lead processing sector are recycling blast furnace slag to the sinter plant, and recovering lead and zinc from the slag by slag fuming. Table 6-8 summarizes best management practices in the processing and refining of lead and silver.

Table 6-8
Best Management Practices in Lead and Silver Processing and Refining

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Air scrubbing	Use wastewater from air scrubber for slag granulation, evaporating all water
Ore processing	Improve ore processing to reduce slag volumes
Blast furnace	Recycle blast furnace slag to the sinter plant
Lead smelting	New furnaces/processes (e.g., Kivcet, Sirosmelt, TBRC, KHD, QSL, which can be completely sealed and thus more easily meet emissions regulations)
Slag	Recover lead and zinc from the slag by slag fuming
Slag	Use slag as a construction material where lead contents allow
Slag quenching	Reuse water used to quench and granulate slag

Recycling Blast Furnace Slag
Blast furnace slag is recycled to the sinter plant in order to recover metals that would otherwise remain in the slag. It is also used to adjust the concentration of lead in the materials being fed to the sinter plant. The slag is blended with the other sinter plant input materials (e.g., ore concentrates, flue dust, and fluxes) to yield a mixture which is pelletized and roasted in the sinter plant. Approximately 36% of the sinter plant=s feed is made up of slag at facilities which recycle slag.

Slag Fuming
Slag fuming is practiced to recover zinc oxides, created through reoxidation of the metals in the bottom portion of the blast furnace. These metals would otherwise remain in the slag. To some extent, lead can also be recovered by slag fuming. In slag fuming the molten lead slag is charged in a fume furnace and a stream of air is injected. Pulverized coal is added to maintain the necessary temperature and control the reducing environment. Using a stream of secondary air above the surface of the slag, the zinc and lead are then reoxidized and collected as particulate matter from the furnace gases.

Waste streams generated from slag fuming consist of the exhaust gas (which contains the zinc and lead being recovered and the volatile components of the blast furnace slag), the remaining slag, and water used to quench and granulate the slag. To control the exhaust gas it is sent to baghouses, where the particles are removed and the volatile components condensed. Since the remaining slag is similar to unfumed slag, it can be used in any of the following ways:

< aggregate in asphalt used to surface roads
< substitute for aggregate in construction block
< frost barrier and buried pipeline bedding material
< air blasting abrasive for removal of paint from concrete and steel structures, as well as the removal of rod paint stripes
< railroad ballast

The water used to quench and granulate slag can be treated and reused.

Air Emission Prevention and Control
Each of the three major lead smelting process steps generates substantial quantities of particulates and/or sulfur dioxide. Emission controls on lead smelter operations are used to capture particulates and sulfur dioxide. Fabric filter and electrostatic precipitators are the most commonly employed high efficiency particulate control devices. These often follow centrifugal collectors and tubular coolers. Sulfuric acid plants can also be used to control sulfur dioxide emissions from sinter machines and, occasionally from blast furnaces.

6.6 ZINC AND SILVER

6.6.1 Typical Wastes

Primary zinc production operations include pretreatment, smelting, and refining/casting. Silver often accompanies zinc in the source ore and the two are processed together until separated at a point dictated by the type of source ore and process used. The primary production of zinc begins with the reduction of zinc concentrates to metal. This is accomplished either pyrometallurgically by distillation or hydrometallurgically by electrowinning.

Primary zinc processing activities generate air emissions, process wastes, and other solid-phase wastes. Air emissions are generated during roasting, which is responsible for more than 90 percent of the potential SO_2 emissions. Much of the particulate matter emitted from primary zinc facilities is also attributable to roasters. Wastewater may be generated during the leaching, purification, and electrowinning stages of primary zinc processing when electrolyte and acid solutions become too contaminated to be reused again. Solid wastes, some of which are hazardous, are generated at various stages of processing. In the U.S., slurry generated during the operation of sulfuric acid plants and the sludge removed from the bottom of the electrolytic cells are regulated as hazardous waste.

Typical waste streams from primary zinc and silver manufacturing include:
< zinc reduction furnace wet air pollution control

< preleach of zinc concentrates
< leaching wet air pollution control
< electrolyte bleed wastewater
< cathode and anode washing
< casting wet air pollution control and contact cooling
< cadmium plant wastewater
< clinker
< geothite and leach cake residues
< synthetic gypsum
< process wastewater
< acid plant blowdown
< wastewater treatment sludge/APC blowdown
< ferrosilicon
< zinc-lead slag

Figure 6-4 shows a schematic diagram of the primary zinc production process.

Figure 6-4
The Primary Zinc Production Process

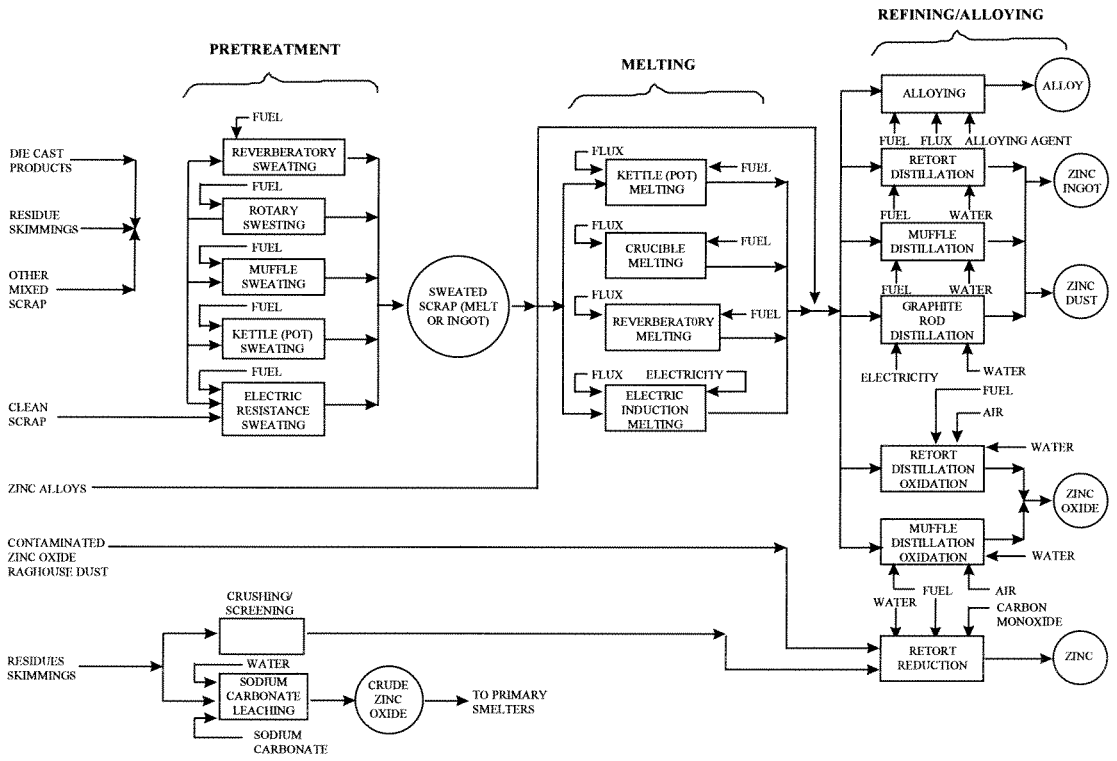


Table 6-9 shows process material inputs and waste outputs in primary zinc processing.

Table 6-9
Process Material Inputs and Waste Outputs in Primary Zinc Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Zinc roasting	Zinc ore, coke	Sulfur dioxide, particulate matter containing cadmium and lead	N/A	Acid plant blowdown slurry
Zinc leaching	Zinc calcine, sulfuric acid, limestone, spent electrolyte		Wastewater containing sulfuric acid	Leach residue, solids containing lead, gold, silver, iron, calcium and silica
Zinc leach solution purification	Zinc-acid solution, zinc dust, copper sulfate, arsenic	N/A	Wastewater containing sulfuric acid, iron	Copper cake, cadmium, nickel, cobalt, antimony
Zinc electrowinning	Zinc in a sulfuric acid/aqueous solution, lead-silver alloy anodes, aluminum cathodes, barium carbonate, or strontium, colloidal additives	Acid mist	Dilute sulfuric acid	Electrolytic cell slimes/sludges

6.6.2 Best Management Practices

Opportunities for waste minimization through raw material substitution are limited by characteristics of the ores that are processed. Selection of source ores and improved ore processing techniques, however, may lead to reduced slag volume in some cases. Other source reduction opportunities may involve process modifications that increase the efficiency of metal recovery during the smelting operation. Table 6-10 summarizes best management practices for the processing and refining of zinc and silver.

Table 6-10
Best Management Practices in Zinc and Silver Processing and Refining

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Leaching	Recycle leaching scrubber water
Furnace slag	Process slag from furnace to return to process or find other use
Zinc extraction	Adjust the amount of zinc slag being returned to the process to maximize extraction
Ferrosilicon	Sell the ferrosilicon separated from the rest of the zinc slag to cast iron foundries as a source of iron
Processed slag	Use processed slag as a drainage material in the flyash landfill
Processed slag	Use processed slag as railroad ballast, road rock, or as an aggregate in asphalt

Sulfur Removal

For efficient removal of zinc, sulfur must be removed from the concentrates to a level less than 2%. This is done by fluidized beds or multiple-hearth roasting, occasionally followed by sintering. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process or by the electrolytic process if high purity zinc is needed.

All slag emerging from the furnace can be processed. The slag can then be separated into four materials: reclaimed coke and zinc-rich fines, which can both be recycled; ferrosilicon, which can be stockpiled and sold to cast iron manufacturers; and processed slag which can be used in construction applications or used in the facilities flyash landfill as a drainage material.

The amount of zinc slag that is recycled can vary, depending on the amount of zinc and coke contained in the slag. This, in turn, is largely a function of how efficiently the retort furnace uses the feed materials, and the nature and quality of the ore and secondary materials being fed to the smelting process. The efficiency of the retort furnace and of the feeding operation can vary considerably from run to run. To extract the maximum amount of zinc from the inputs, a facility should adjust the amount of zinc slag being returned to the process. This means that increased recycling efforts have small potential for further reducing the amounts of slag being generated.

Reusing Processed Slag and Ferrosilicon

Ferrosilicon, which is magnetically separated from the rest of the zinc slag, can be sold to cast iron foundries as a source of iron. Processed slag can be used as a drainage material in the flyash landfill, as railroad ballast and road rock (gravel), as an aggregate in asphalt, and as an anti-skid material.

Air Pollution Control
Dust, fumes, and sulfur dioxide are emitted from zinc concentrate roasting or retorting operations. Particulates can be removed by electrostatic precipitators or baghouses. Sulfur dioxide can be converted directly into sulfuric acid. Baghouses are most commonly used to recover particulate emissions. A cyclone and baghouse together can achieve recovery efficiencies greater than 99.7%. Baghouses alone can also achieve efficiencies in the high 90's. Baghouses show similar efficiencies in removing particulates from exhaust gases of melting furnaces.

6.7 GOLD AND SILVER

6.7.1 Typical Wastes

Primary gold production operations include precipitation or carbon-in-pulp recovery, desorption/stripping, and refining. Silver typically accompanies gold in the ore and the two are processed together until separated at a point dictated by the type of ore and process used. When gold is associated with copper ores, it travels with the base metal through concentration and smelting to the refining stage. It is eventually separated from the anode slimes that accumulate in electric copper refining cell and is recovered as gold bullion in the precious metals refinery. Gold losses in concentrating copper ores are about the same as for copper, but are negligible in smelting and refining. Typical waste streams from primary gold and silver manufacturing include:

< smelter wet air pollution control
< silver chloride reduction spent solution
< electrolytic cells wet air pollution control
< electrolyte preparation wet air pollution control
< calciner wet air pollution control
< calciner quench water
< calciner stack gas contact cooling water
< mercury calcining condensate
< mercury cleaning bath water
< particulate control effluent
< furnace calcines

Table 6-11 shows process material inputs and waste outputs in primary gold processing.

Table 6-11
Process Material Inputs and Waste Outputs in Primary Gold and Silver Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Ore roasting and autoclaving	gold and silver concentrate and ore	sulfur oxides, mercury, volatile metals, steam	spent calcined ore, tailings,	waste water
Gravity separation	gold and silver ores	usually none, wet process	tailings, wash water,	black sands and sulfides
Amalgamation	concentrates	mercury vapors	concentrate residues, tailings	retort residues, cooling water
Flotation	primary ores, flotation reagents	VOC=s from flotation reagents	solid tailings, water in tailings slurry, spent reagents from the rougher and cleaner circuits	mill maintenance wastes such as open gear lubes, solvents, worn mill liners, worn grinding balls
Vat Leaching	primary ores	HCN	tailings solids and liquids, chemicals used in solution neutralizing	
Heap Leaching	primary ores	HCN	spent heaps, neutralized solutions	rinse waters, leachate seepage
Recovery of gold and silver from leach solutions	pregnant leach solutions	HCN, Ammonia,	spent and undersize carbon,	neutralized solutions and rinse waters
Regeneration of carbon	carbon, coconut shells, hydrochloric and nitric acids	Hydrochloric acid mists, Nitric acid mists, ammonia	reacted nitric and hydrochloric acid from carbon regeneration	sludges and insols
Melting and refining of gold and silver dore and bullion	fluxing agents, dore, splash and slag, laboratory assay buttons, electrowinning cathodes, anode slimes, gravity concentrates	volatile metals, mercury, particulates containing fluxing reagents, sometimes SO_2 from sulfide minerals	slag, dust collector system blowdown, collected dusts,	refractory brick, bullion and dore molds
Assay laboratory	cupels, lead reagent, crucibles	fumes with volatile metals	used cupels, used crucibles, slag	spent laboratory chemicals

While technically not a part of metal processing, many gold mining operations recover gold from cyanide leach solutions by precipitation with zinc dust. In recent years though, carbon-in-pulp (CIP) recovery technology has been adopted at a number of new mining operations. With CIP, activated carbon, made from coconut shells or other durable carbon sources, collects gold from the cyanide pulp until it contains 10 to 12 kg of gold per ton of carbon. Gold with accompanying silver is desorbed or stripped from the carbon with a strong alkaline cyanide - alcohol solution.

The precious metals are recovered from the strip solution by electrodeposition on a stainless steel wool cathode. Gold leaching processes in use or under development that do not employ cyanide as the principal lixiviant or dissolution medium include the application of thiourea, iodine, chlorine, bromine, malononitril, or various bioextraction techniques. Some of these techniques may be accompanied by unacceptable cost or environmental burdens.

Environmental concerns associated with gold mining include many of the same issues that are typical of other metal mines. Special monitoring procedures should be employed to ensure full recovery of cyanide in milling or heap leaching plants.

Because of hazards associated with mercury=s toxicity, the use of mercury amalgamation in U.S. gold operations is almost nonexistent. Other potential pollutants that may be byproducts from gold mining include antimony, bismuth, tellurium, and thallium.

6.7.2 Best Management Practices

Table 6-12
Best Management Practices in Primary Gold and Silver Processing

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Milling and heap leaching	Use special monitoring procedures to ensure full recovery of cyanide
Mercury amalgamation	Do not use this method except under a completely controlled laboratory condition. The environmental and health impacts are too great.
Gravity separation	Use settling ponds
Gravity separation	Use decant devices
Gravity separation	Thicken and filter tailings before discharging to waste ponds
Gravity separation	Use mill-thickener-mill head tank process loop instead of mill-tailings pond-reclaim barge-mill head tank loop. It is shorter and reduces evaporative losses or seepage, and allows for better recycle percentages
Flotation of gold in mill circuit	Use a closed loop system for reclaiming tailings water, using thickeners and substituting degradable flotation aids for noxious reagents
Cyanide vat leaching	Practice reagent conservation. Maintain adequate caustic to keep the pH in the stable and reagent-conserving range of about 10.5.
Cyanide vat leaching	Use cyanide recycling technology
Cyanide heap leaching	Keep track of the effective cyanide strength in the leach solutions to

UNIT OPERATION	BEST MANAGEMENT PRACTICE
	optimize dosages.
Cyanide heap leaching	Add rinse waters from a retired heap to the make-up water for an active heap to conserve water, reuse cyanides, and increase the life of spent ore heaps.
Cyanide leach solutions	Use chemicals efficiently and minimize generation of pollutants such as ammonia during electrowinning
Dore production	Use a dust control device to recover trace metals produced during the dore melt

Gravity Separation

The concentration of gold using conventional water separation techniques has changed little over hundreds of years. The ability to control and recycle the water continues to improve, however, and almost 100% water recycle is now required in most modern mines.

Best management practices for handling the wastewater from water separation techniques include the use of settling ponds, decant devices, filtration designs in tailings ponds, and thickening or filtering of tailings before waste streams reach the ponds. The process loop from mill to thickener to mill head tank is shorter than the process loop from mill to tailings pond to reclaim barge to mill head tank. The shorter loop is subject to less evaporative or seepage loss and allows for better recycle percentages.

Amalgamation Using Mercury

Mercury has been widely used to separate gold from black sands for many years. Those who have worked in the gold fields are well aware of the debilitating effects of ingesting and inhaling mercury fumes. Modern gold mining makes little use of mercury amalgamation except on the smallest scale and at the most primitive of facilities. Unfortunately, these are the same types of facilities that may be only partially aware of the hazards of working with mercury. The practice of driving mercury out of amalgam in open circuit to the atmosphere is particularly dangerous.

Mercury amalgamation should be considered as a method for separating and concentrating gold only if all other collecting and concentrating techniques have been eliminated. Jig tables, spiral separators, gravity column cells, and conventional riffle devices can be used to concentrate the fine gold for further refining by cyanidation, fire, or direct smelting techniques. Gold processing using mercury amalgamation should never be done anywhere but in a controlled laboratory environment. Where amalgamation is still practiced, complete retorting recoveries and sealing of amalgam during storage and shipment would prevent vaporization and loss of mercury to the environment, thus allowing continuous recycle.

Flotation of Gold in Mill Circuit

Gold recovered in flotation circuits is usually in the form of a combined alloy (free gold) or as an inclusion in pyrite or other metal sulfides. Flotation aids and reagents vary in terms of toxicity and other noxious characteristics. Some, like xanthates, generally break down and are not considered persistent environmental contaminants. Others, such as potassium dichromate (used as an oxidant in some circuits), Nokes reagent (contains phosphorus pentasulfide), or sodium cyanide (sometimes used to depress pyrite flotation), may be toxic and/or nondegradable.

Best management practice is a closed loop system for reclaiming tailings water, using thickeners and substituting degradable flotation aids for noxious reagents.

Cyanide Vat Leaching

The use of confined vats for leaching of gold ore slurries is a practice pioneered in New Zealand about a century ago. The method is preferred where ore grades are high, permeability through heaps is questionable, breakdown of the rock matrix would compromise recoveries, or where physical limitations demand an alternative to heap leaching. The technology utilizes several different means of moving pulped ore countercurrent to leach liquors. Ammonia generated during cyanide attrition and volatilization of hydrogen cyanide gas from the tank surfaces are the two major environmental concerns.

Best management practices at cyanide vat leaching operations are closely tied with common sense reagent conservation and safety requirements. Sodium cyanide solutions are extremely dissociable and become volatile as HCN at low pH. Sodium cyanide solutions are extremely stable at a pH of 10.0 to 10.5 or higher. The BMP is to maintain adequate caustic to keep the pH in the stable and reagent-conserving range of 10.5 or thereabouts.

Another BMP at vat leaching operations is the use of cyanide recycling technology. Off-the-shelf technology is available to shorten the loop of cyanide. Conventional technology sends the cyanide through the mill once and then either to the tailings pond for decant and recovery or to cyanide destruction using peroxide, SO_2, copper sulfate, or ferrous sulfate. Cyanide recycling technology adds a step just before final discharge into the tailings pond. During this last step, the barren pulp is treated to pH just low enough to allow the volatilization of HCN to be effectuated by sparging compressed air through an agitated reaction chamber. The off gases are blown through a caustic scrubber with a packed tower that recovers the cyanide as sodium cyanide for pumping directly back into the mill. The process is in commercial application at several mines worldwide. (Cyanasorb is the registered trademark of one such technology.)

Cyanide Heap Leaching

The use of heap leach technology for gold recovery has revitalized the gold industry by allowing commercial recoveries of 70-80% or more from ore grades as low as 0.02 ounce per ton and lower. (The recovery of silver from heaps is much less effective and requires much higher concentrations of cyanide in the leaching solutions.) Both gold and silver recoveries are limited in some cases by competing cyanophilic metals such as copper and iron. To counteract the cyanide losses to other metals, sometimes higher recirculating loads of cyanide are created.

The BMP for minimizing buildup of cyanide compounds is to keep track of the effective cyanide strength in the leach solutions. The easy approach of Aa little is good, more is better≅ may not be economically necessary in some cyanide heap leach operations.

Another BMP for cyanide heap leach operations is to add rinse waters from a retired heap to the makeup water for an active heap. This can conserve water, reuse residual cyanides, and perpetuate the life of spent ore heaps.

The use of buried wobbler or distribution emitters should also be considered. Common practice has been to expose the lixiviant to atmosphere to encourage coverage, allow inspection, and to maximize spreading. The growing experience of miners in cold climates where emitters have been covered to prevent freezeup has shown no loss of production, and there is some feeling that the protection from evaporation and loss of volatile cyanides could be conserving reagents.

Recovery of Gold from Cyanide Leach Solutions

The separation of gold from the cyanide solutions, known as the strip step, is the last process before the solutions move on to the vat, heap, or tailings pond. The efficiency of the strip step is dependent on a number of factors, including the type of technology employed. The choice of technology should be based on the best metallurgical and economic information available but it should be remembered that conditions change. There are changes in mine reserves, in market conditions, in the depth of ore deposits, and in the needs of custom mills that may shift their interest to and from silver or gold.

At high silver mines, it is typical to use a zinc powder to collect the valuable metals from the pregnant leach liquor. At low silver mines, an electrowinning process is commonly used, where gold is plated out of solution onto anodes. Sometimes both technologies are available.

Best management practices for recovery of gold from cyanide leach solutions are: efficient use of chemicals, minimal generation of pollutants such as ammonia during electrowinning, and maximum recovery of the target metals. It is unlikely that many mines do not already practice BMP for this step, because the BMP are closely tied to commercial efficiency.

Dore Production
The production of dore bar is common at many mines. The ingot or bar is the end of the production circuit and for security reasons this step is usually done in a room with limited access. A typical gold bar may weigh over 25 kilograms. In the process of casting the bar, there may be other trace minerals released in the volatile gases that come off the ladle and crucible. Mercury and lead are commonly associated with the off gases, although usually at low concentrations.

To recover the trace metals produced during the dore melt, a dust control device should be used.

6.8 TIN

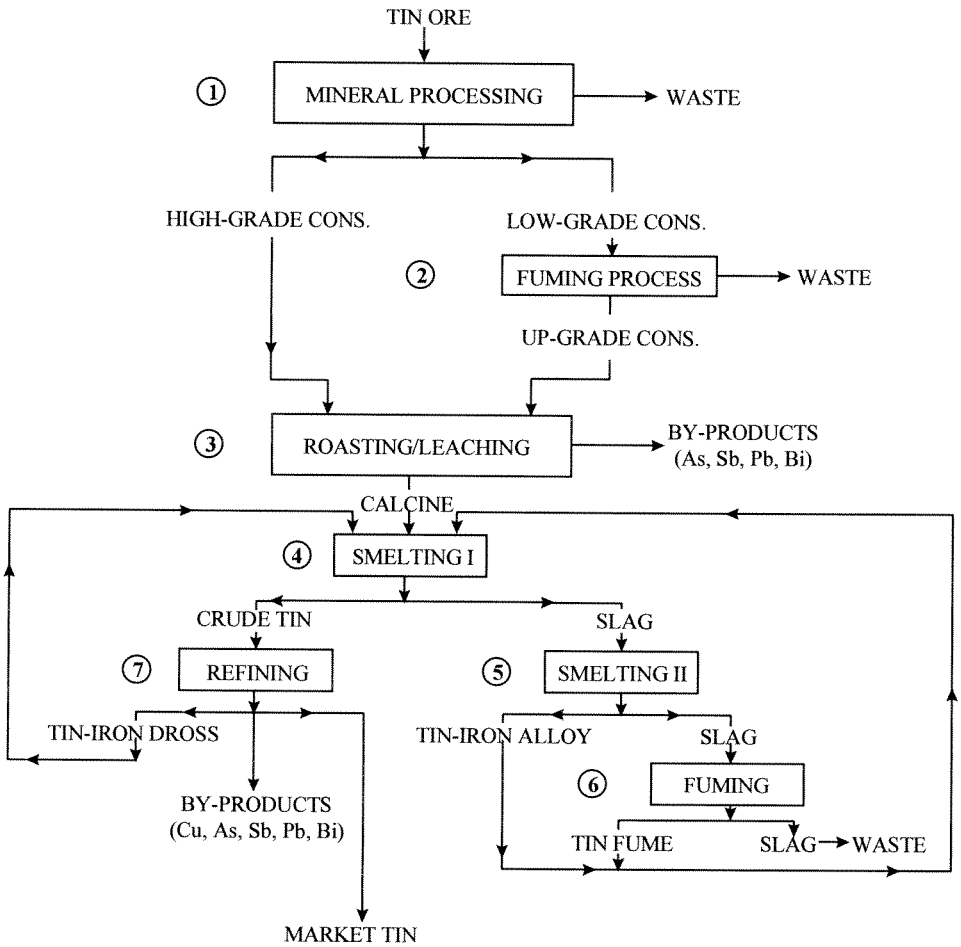
6.8.1 Typical Wastes

The primary tin production process traditionally consisted of a two-step smelting process, followed by refining of the crude tin. The main concern in tin smelting is the separation of iron, an element which behaves in a manner similar to tin during smelting. Concentrates are first smelted with a limited amount of reducing agent (coke) to produce a fairly pure crude tin with as little iron as possible and a tin-rich slag containing most of the iron. The tin-rich slag is then smelted at a higher temperature with more reducing agent to produce a tin-iron alloy (which is recycled back to the first stage of smelting) and a slag which may be discarded or treated for additional tin recovery by fuming if warranted. The crude tin from stage one smelting is sent to refining.

In recent years tin concentrate grades have declined and impurity levels in concentrates have risen as higher grade ore deposits have been worked out. Impurities typically found in tin concentrates include lead, bismuth, arsenic, antimony, zinc, copper, iron, and silver, usually in the form of sulfide minerals. In order to cope with these problems, primary tin producers have added operations such as roasting, leaching, and fuming to the traditional smelting/refining plants to eliminate these impurities before the smelting stage and to maintain or increase tin recovery.

Figure 6-5 shows a schematic diagram of the primary tin production process.

Figure 6-5
The Primary Tin Production Process



Source of this diagram is: Davey, T.R.A., Advances in Lead, Zinc, and Tin Technology -Projections for the 1980's, in Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control, eds. John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, AIME, 1979.

Primary tin processing activities may result in air emissions, process wastes, and other solid-phase wastes such as slags. The primary air emissions from tin processing are substantial quantities of SO_2 and particulates. Gases, fumes, and dusts are given off by the roasting, smelting, and fuming steps. Chemical constituents in these wastes include the whole range of impurity elements found in the feed concentrates mentioned above.

Typical waste streams from primary tin production include:

< roasting plant air pollution
< smelting plant air pollution
< fuming plant air pollution
< leach plant residue, precipitates, and liquids
< refining plant slags and drosses
< smelting slags
< spent furnace brick
< facility washdown
< employee hand wash
< laundering of uniforms
< acid plant blowdown
< acid plant sludge
< baghouse dust
< process wastewater

Table 6-13 shows process material inputs and waste outputs in primary tin processing.

Table 6-13
Process Material Inputs and Waste Outputs in Primary Tin Processing

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
Tin Smelting	Tin concentrate or roasted calcine, limestone flux, recycled hardhead, fume, and dross, coal/coke	Sulfur dioxide, particulate dusts containing arsenic, antimony, bismuth, lead	N/A	Slag containing mainly lime, silica, ferrous oxide with some stannous oxide, Zn, Co, Au, Ag
Tin Roasting	Tin concentrates, recycled arsenic dross, gas cleaning dust	Sulfur dioxide, particulate matter containing arsenic, antimony, iron, copper, bismuth, and zinc	N/A	N/A
Tin Fuming	Low-grade tin concentrate, smelting slag, pyrite, oil	Sulfur dioxide, particulate matter containing tin and metallic impurity elements (As, Sb, Bi, Pb)	N/A	Slag/waste containing Zn, Co, Ni, Cu; low-grade tin concentrate residue
Tin Refining (pyrometallurgical or electrolytic)	Crude tin, sulphonic acid (electrolyte), air, sulfur, Al/Na/Ca/Mg,	N/A	N/A	Arsenic dross, tin-iron dross, by-products (Cu, As, Sb, Pb, Bi), anode muds

Process	Material Input	Air Emissions	Process Wastes	Other Wastes
	chlorine			

6.8.2 Best Management Practices

Opportunities for waste minimization through raw material substitution are limited by characteristics of the ores that are processed. The present trend is toward more complex lode or Ahard rock≅ ores containing greater levels of impurities, since the Acleaner,≅ higher-grade placer ores are becoming exhausted. Selection of source ores and improved ore processing techniques, however, may lead to reduced slag volume and better recovery of both tin and byproduct metals in some cases. Other source reduction opportunities may involve process modifications that increase the efficiency of metal recovery during the refining operation, such as vacuum distillation. The most prominent waste minimization practices currently employed in the primary tin processing industry are recycling the various slags, as well as the fumes and dusts collected by the gas cleaning systems, back into the tin and byproduct recovery process.

Table 6-14 summarizes best management practices in the processing and refining of tin.

Table 6-14
Best Management Practices in Tin Processing and Refining

UNIT OPERATION	BEST MANAGEMENT PRACTICE
Ore Processing	Improve ore processing technology to increase recoveries and reduce slag volumes and toxicity of solid and liquid wastes
Smelting	Recycle slag to the process for metal recovery
Smelting	Add second-stage slag fuming for additional tin recovery
Smelting	Use slag as a construction material
Refining	Use centrifuges for fully automated removal of drosses containing Fe, Cu, As, Sb, and Bi in a more hygienic manner at less cost; also reduces need to upgrade concentrates before smelting
Refining	Use vacuum distillation to remove Pb, Bi, As, Sb without labor and hygienically; also reduces need to upgrade concentrates before smelting
Fuming	Replace mineral processing and smelting with a fuming process
Off-gas scrubbing/cleaning	Recycle minor elements to process for recovery; capture sulfur for manufacture of sulfuric acid/elemental sulfur
Various metal-bearing wastes	Recover metals from metal bearing wastes
Pyrometallurgical processing	Implement new types of furnaces/processes (top blown rotary converter, Sirosmelt, Ausmelt, etc.) for improved recovery, ease of operation and increased environmental benefits

Recycling Slag and Dross
A wide variety of smelting slags, arsenic dross, and tin-iron dross from refining is recycled to the smelting furnace in order to recover metals that would otherwise remain in the slag and dross. These materials are blended with the other input materials (e.g., ore concentrates, flue dust, and fluxes).

Slag Fuming
Slag fuming is practiced in some plants to recover tin from the second-stage smelting slag. Tin is volatilized as an oxide, filtered from the gases, and recirculated to the smelting furnace. This metal would otherwise remain in the slag.

Concentrate Fuming
High-grade tin concentrates with high tin recoveries are becoming less available. The average tin content is falling and the amounts of associated sulfide impurities (such as Pb, Bi, As, and Sb) are increasing. There is a need for processes that can accept low-grade concentrates which are heavily contaminated with heavy metal sulfides. Fuming of low-grade concentrates can result in a higher grade material (40-50% tin) at over 90% recovery, which is suitable for leaching or smelting. In some cases, fuming of low-grade ores or concentrates could replace mineral processing (ore processing, beneficiation) altogether, especially if the ore contains sufficient combustible material in the form of high value fuels such as pyrite/pyrrhotite. In this case, the resultant sulfur dioxide gases would have to be captured, and ideally, utilized as byproduct sulfuric acid. An advantage of this type of fuming is that tin losses during concentration could be minimized or avoided since there would be no need to accept tin recoveries as low as 50% during concentration in order to produce a high grade concentrate. In addition, it may be easier to isolate and recover the contaminant metals.

Air Emission Prevention and Control
Smelting, roasting, and fuming generate substantial quantities of particulates and/or sulfur dioxide. Emission controls on tin smelter operations are used to capture particulates and sulfur dioxide. Fabric filter, baghouses, wet scrubbers, and electrostatic precipitators are the most commonly employed particulate control devices. Sulfuric acid plants can also be used to control sulfur dioxide emissions.

Developments in furnace and process design are leading to a number of types of furnaces/processes (e.g., top blown rotary converter, Sirosmelt, Isasmelt, Ausmelt, etc.) which not only improve process economics and metallurgical efficiency, but are capable of being sealed fairly completely from the atmosphere. These new technologies meet more stringent

environmental regulations through the capture, separation, and possible recovery of sulfur dioxide gas and contaminant metals into marketable form.

CHAPTER 7
ESTABLISHING ENVIRONMENTAL MANAGEMENT SYSTEM (EMS)

One of the best approaches for a mining company to improve its environmental performance is to develop, implement, and maintain an environmental management system (EMS). An EMS helps a company to organize its environmental needs in the same way it organizes its marketing, research, financial, communications, and other business needs. It is expected that sound environmental management will lead to improved environmental performance.

Potential benefits associated with implementing an EMS are:

< demonstrating commitment to environmental management;
< enhancing public image and market standing;
< meeting supplier certification criteria;
< improving cost control;
< conserving input materials and energy;
< facilitating the process of obtaining local licenses and authorizations; and
< improving industry-government relations.

7.1 INTRODUCTION TO ISO 14000

The basic components of an EMS are specified in the ISO 14000 series of voluntary standards that have been developed by the International Organization for Standardization (ISO). ISO 14001 is the standard that details the basic requirements of an effective EMS. Since mining is an exporting industry, mining companies may feel special global market pressures to seek certification to this international standard.

ISO 14001 is not intended to serve as a substitute for or supplement to national environmental laws and regulations. It purposely refrains from establishing specific performance levels and rates of improvement. Instead, the standard provides a framework that allows individual

companies the flexibility to establish their own policies and performance objectives which may go beyond the current regulatory requirements.
Some mining companies may find that the benefits of adopting ISO 14001 outweigh the costs, while others will find the opposite is true. Even if ISO 14001 certification proves unfeasible, the company may decide to put an EMS in place for its own management reasons, e.g., reductions in waste disposal costs, liability, or to improve worker and community relations.

The following sections describe the main components of EMS development and implementation that need to be established independently of whether or not the company decides to pursue ISO 14001 certification.

7.2 EMS DEVELOPMENT

7.2.1 Environmental Policy Formulation

The first step in designing an EMS is to formulate and state the environmental policy for the company. The environmental policy sets the basic principles of environmental responsibility by which the company wishes its performance to be judged. It provides a sense of the company=s direction and commitment to the environment and a framework for setting goals and objectives.

The environmental policy should include the following commitments on the part of the company:

< To comply with all environmental regulations and, to the extent possible, to engage in environmental protection efforts beyond the legal requirements.

< To pursue sound environmental management practices which allow for continued improvement within the environmental management system.

< To manufacture products in a manner that reduces releases to the environment through the use of pollution prevention techniques.

7.2.2 Review of Environmental Impacts and Aspects

The company should review the following environmental aspects of its operations and their impacts on the environment:

< air emissions
< wastewater discharges
< solid waste management
< energy use

< water use
< land use

There are various techniques for evaluating environmental impacts. The most typical approach involves examination of individual processes, which is often referred to as Aenvironmental audit,≅ or, if it is used to assess compliance with environmental regulations, Aenvironmental compliance audit.≅ Other techniques include emission inventory, risk assessment, process hazard analysis, and pollution prevention audit.

The first step in assessing environmental impacts and operational inefficiencies is to conduct input materials and waste stream characterizations. Much of the information required for this is already available from the day-to-day operating records and regulatory reports and permits. Site inspections and worker interviews should be used to collect missing data, verify available data, and identify elements that may not be well-documented.

Wastewater streams from all sources should be analyzed, e.g., mine water drainage, process water, drainage from overburden and ore stockpiles, surplus water from the filter plant, and leachate from tailings dams. Methods used for wastewater treatment should be assessed and their effectiveness evaluated. Dust emissions to the atmosphere from mining ventilation and from crushing operations should be reviewed with respect to potentially harmful dusts. The nature and quantities of all potentially hazardous materials (including fuel) held on the premises should be identified. The safety of storage locations must be evaluated, and the safeguards for containing these materials and ensuring clean-up of accidental spillage should be described. Housekeeping practices, spill clean-up, and leak control methods should also be noted.

7.2.3 Identification, Evaluation, and Selection of Improvement Options

Once the review of environmental impacts and aspects is completed, the selection of improvement options begins, drawn from these broad categories:

< waste reduction at source
< reuse of input materials and in-process recycling
< energy efficiency improvements
< reduction of water use

The most promising options need to be identified for feasibility analysis, a process that aids the decision-maker in selecting options for possible implementation.

Feasibility analysis is accomplished in five steps:

1. *Preliminary evaluation:* The options are sorted in order to identify further evaluation needs. Improvements in management methods and practices do not always require a technical evaluation, while equipment-based options do. Similarly, cheap options do not require a detailed economic evaluation, but expensive options do.

2. *Technical evaluation:* The technical evaluation consists of two interrelated parts. First, it should be determined whether the option could be put into practice. For example, the availability and reliability of equipment, the effect on productivity and product quality, the expected maintenance and utility requirements, and the necessary operator and supervisor skills must all be considered. Second, the technical specifications of the option under consideration should be converted into a projected materials balance to show the input and output material flows and energy requirements.

3. *Economic evaluation:* The economic evaluation consists of data collection regarding capital and operational costs and benefits, the choice of an evaluation criterion (payback period, net present value, or internal rate of return), and feasibility calculations. The economic data collection builds upon the results of the technical evaluation.

4. *Environmental evaluation:* The environmental evaluation is based on the comparison of the current materials balance (derived in the audit phase) and the projected materials balance (derived in the technical evaluation). Environmental improvement occurs if the total quantity of pollutants is reduced or if the final waste streams contain less hazardous materials.

5. *Selection of feasible options:* First, the technically or economically nonfeasible options can be eliminated, along with the options producing no significant net environmental benefit. All remaining options can, in principle, be implemented. However, further choices must be made if the options are mutually prohibitive or if funding limitations do not allow the implementation of all the feasible options.

7.2.4 Developing an Environmental Management Program

Developing an environmental management program includes (1) setting objectives and targets related to the options selected for implementation and (2) defining schedules, resources, and responsibilities for achieving the objectives and targets.

Objectives are long-term goals and targets are short-term steps toward achieving these goals. Targets should be specific, measurable, and have concrete timeframes. When establishing and reviewing its objectives, the company should consider the legal and other requirements pertaining to its activity, its significant environmental impacts, the identified improvement

options, and financial, operational, and business requirements. The objectives and targets should be consistent with the firm=s environmental policy.

Objectives and targets can apply across the company or on a site-specific or activity-specific basis. An operator of a small mine may establish a single set of objectives to cover all phases of the operation. A large company with several mines may choose to develop an environmental management program with broad goals, supplemented by individual goals for each specific operation and possibly even for various operating departments. An overall objective of a 50% reduction in wastewater discharges may translate into specific reduction targets applicable for each operation.

It is the company management=s responsibility to:

< designate responsibility for achieving objectives and targets at each relevant function and level;

< provide the means of fulfilling the objectives and targets; and

< designate a timeframe within which they will be achieved.

Objectives and targets should be periodically reviewed and revised. It is essential to determine the measures that will be used to track progress. The management should communicate the objectives and targets (as well as the progress in achieving them) across the company.

Some companies will integrate the EMS with other planning efforts, such as strategic planning. Others will find it easier to maintain the environmental management system as a separate initiative. Whether an integrated or an independent approach is used, an effective environmental management program will consist of action steps prioritized in order of their importance to the company. These actions may deal with individual processes, sites, or facilities within a site.

7.3 EMS IMPLEMENTATION

7.3.1 Defining Implementation Responsibilities

The company should define, document, and communicate to all employees the roles, responsibilities, and authorities of those involved in EMS implementation and provide the necessary human, financial, and technical resources. It is advisable to assign a management representative to the project to ensure that the EMS is maintained and implemented. This individual would be responsible for reporting on the performance of the EMS to the top management.

The following questions can help your company determine the right organizational structure for environmental management:

< Look at the scope of your environmental management program: What capabilities do you need? Who needs to be involved to make the system effective? What training or other resources will these individuals need?

< Look at your significant environmental impacts. What operations/activities need to be controlled? Who needs to be involved to ensure that controls are implemented?

< Look at the results of previous audits or other assessments: What does this information tell you about the effectiveness of your company=s organizational structure? How could it be improved?

< Look at the current responsibilities for environmental management: How can you enhance commitment to environmental management across the firm? How can other business functions support the EMS?

< Look at your quality management and/or other existing management systems: What are the roles and responsibilities? Where are the opportunities for integration?

It is important to note that environmental performance is not solely the environmental manager=s responsibility; the entire company should be involved. There are several helpful approaches to the subject of environmental responsibility:

< Distribute environmental responsibility to managers across the company and to employees whose work is relevant to the environmental objectives.

< Provide regular feedback to the management and employees on the company=s progress in achieving objectives and targets.

< Communicate to people what their duties are (as well as the roles of others). One of the tools for communicating responsibilities is a responsibility matrix. All employees must understand their role in achieving the targeted environmental performance and become aware of the potential environmental aspects of their jobs. Table 7-1 provides examples of how various existing functions within the company can be augmented in order to provide support to the EMS.

Table 7-1

How Various Employee Functions Can Support the EMS

Functions		How They Can Help (Possible Roles)
Purchasing	<	Develop and implement controls for chemical/other material purchases
Human Resources	<	Define competency requirements and job descriptions for various EMS roles
	<	Integrate environmental management into reward, discipline, and appraisal systems
Maintenance	<	Implement preventive maintenance program for key equipment
Finance	<	Track data on environmental management costs
	<	Prepare budgets of environmental management program
	<	Evaluate economic feasibility of environmental projects
Engineering	<	Consider environmental impacts of new or modified products and processes
	<	Identify pollution prevention opportunities
Top Management	<	Communicate importance of EMS throughout the company
	<	Provide necessary resources
	<	Track and review EMS performance
Line Works	<	Provide first-hand knowledge of environmental aspects of their operations
	<	Support training for new employees

7.3.2 Employee Training

In addition to employee commitment, the EMS requires employee competence. The identification of training needs is directly related to the identification of the company=s environmental impacts. The training program should be designed to raise the level of general environmental awareness among the employees and educate individual system operators about environmental aspects of performing specific assignments.

Training Needs

Environmental awareness training must make employees at all relevant levels aware of:

< their roles and responsibilities within the context of the EMS;
< significant environmental impacts, actual or potential, of their work activities;
< importance of conforming with environmental policies, procedures, and EMS requirements;
< environmental benefits of improved personal performance; and
< consequences of violating procedures.

In addition to operators and line managers, awareness training should be available to employees at all levels, from senior management down to the most junior individuals of the company.

System operators= training should ensure that operators can perform their duties with minimum impact on the environment.

Training Program

For environmental awareness training, classroom training may include:

< an overview of the company=s environmental policy and environmental management program;

< a step-by-step review of operational procedures that apply to environmental protection;

< a video showing environmental management practices such as pollution prevention, source reduction, and recycling;

< a panel discussion of managers describing environmental objectives and targets for their areas;

< a review of the emergency plan and safety procedures; and

< written exercises and discussions about the individual employee=s role in environmental management.

For system operators= training, classroom training may include:

< a video about environmental problems caused by operational errors;
< a review of operating procedures; and
< a review of troubleshooting techniques and corrective actions for nonconformance situations.

Training may also have a field instruction component which may involve:

< hands-on demonstration of environmental aspects of running an operation;
< field review of alarms, monitoring equipment calibration procedures, bypasses, overflows, and redundant equipment; and
< mock drills of equipment malfunction and emergency response.

The company=s management must continuously evaluate and improve the training program and help each employee establish personal goals in performing individual operations.

7.3.3 EMS Monitoring and Programmatic Adjustments

The final step in establishing an EMS is to check and monitor the system, discover problems and correct them. The objective of monitoring is to ensure that environmental objectives and targets are met. The company should develop procedures for:

< monitoring and measuring on a regular basis the key characteristics of operations and activities that can have a significant impact on the environment;

< recording information to track performance, operational controls, and conformance with environmental objectives and targets;

< periodically evaluating compliance with relevant environmental legislation and regulations.

It is important to record the information describing the ongoing operations of the EMS. The records should be accurate and complete.

If monitoring information shows nonconformance with the objective and targets of the company=s environmental management program, corrective action should be taken. The idea is not just to identify the problem but to understand why it occurred and to change the system so that it does not recur.

The management system for handling nonconformance would typically include the following key steps:

< identify the problem
< identify the cause (investigate)
< come up with solution
< implement solution
< document solution
< communicate solution

There are many approaches that management can use to structure its reviews. In general, these will involve a combination of formal and informal methods. Formal methods include:

< Regular update and review of a given set of program and process measurements;

< In-depth review of program and process elements, such as requirements, procedures, measurements, control points, etc.;

< Review of nonconformances; and

< Review of environmental policy, EMS, and strategy for continual improvement.

Senior management may also use informal methods to stay in touch with the EMS operation. For instance, by interacting with employees in their work area, executives can observe environmental management practices in the company first hand, and can seek employee suggestions about how to improve the EMS. Another useful means of getting informal input is to engage in discussions with peer executives managing similar operations or issues. Finally, unscheduled reviews can take place as problems arise that need to be resolved immediately.

An effective EMS for a mine site functions the same way a good safety program does. The focus is on prevention, recognition of potential impacts, correction of deficiencies, continual improvement, and measurement of progress.

APPENDIX A
CASE STUDIES

Selected case studies at active sites are presented in this section. The active sites selected as case studies were not selected as either good or bad models, but rather to examine a range of cyanide treatment techniques. The three active case studies highlight a vat leach operation with INCO treatment of tailings slurry, a large leach heap operation with several heap pads, and a site using biological treatment by bacteria. Material for the case studies came from publicly available documents, and file materials collected from the respective State regulatory offices. The Agency has not evaluated the efficiency on any of the models presented. Rather, this section was developed for informational purposes only.

A.1 HECLA, YELLOW PINE, IDAHO

Hecla Mining Company completed gold extraction from its heap leach pad at Yellow Pine, Idaho in 1992 (Minerals Today). Currently, the facility is detoxifying the cyanide in the spent ore by applying a bacterial biological treatment method to the heap.

The bacterial solution is applied to the spent heap using sprinklers to spray the top of the heap. The solution then percolates through the spent ore with bacteria consuming the cyanide as it progresses. After the solution passes through the heap it is collected in a process pond and then recycled back through the heap. At the end of treatment, the solution pond will be allowed to evaporate, materials (sludges) will be sampled and analyzed, and the unit will be closed in place by folding the pond liner over any remaining sludge, contouring, and revegetating. Information on the type of bacteria, additional nutrients required, and the developer of the process used by Hecla have not yet been obtained. (Idaho 1993)

After treatment, effluent from the heap reached the 0.2 mg/1 state standard for cyanide during the fall of 1992. The Idaho DEQ wants to review cyanide levels through one wet rainy season prior to approving the start-up of reclamation activities. The facility planned to collect effluent samples during spring sampling. Depending on the results of this sampling, the state may approve initiation of reclamation for Fall 1993. (Idaho 1993)

The detoxified heap may not require capping. The fourth (top) tier of the heap will be removed and used to regrade and contour the heap. A berm will be constructed around the top of the heap to prevent runoff erosion from destroying the steep slopes of the heap. The liner beneath the heap will not be broken with numerous perforations, but approximately three spots will be used to drain any percolated material to the ground. The state will require 5 to 10 years of groundwater monitoring of onsite wells (for cyanides and metals). (Idaho 1993)

An Idaho representative (Idaho 1993) stated that the biological cyanide destruction process has appeared to work well at the Yellow Pine facility. The site has been able to meet the 0.2mg/1 WAD cyanide standard for heap effluent, although the state is still waiting to see the results after a wet season, before it approves closure. Metals have not been a problem at the site, although the state representative credits this to the composition of the ore rather than the result of the biological treatment process.

A.2 ZORTMAN MINING, LANDUSKY HEAPS, MONTANA

Zortman Mining, Inc. of Zortman, Montana (a subsidiary of Pegasus Gold Corporation) operates several heap leach pads, a processing plant, and barren and pregnant leachate solution ponds. The Landusky reclamation plan was approved in 1990 by the BLM and the Montana Department of State Lands. The heaps are low-grade run-of-mine ore (neither crushed nor agglomerated) that were leached in 25-foot high lifts. (Fitzpatrick 1992; Schafer and Associates 1991a) A Montana state file lists the site as one of the 13 largest metal mines in Montana, processing 75,000 tons of ore a day. The heaps and tailings cover 175 acres and contain 60 million tons of material.

Being one of the first mines permitted under the 1974 Montana Metal Mining Reclamation Act and the first large-scale gold heap leaching operations in the US (operations began in 1979), the Zortman/Landusky site represents the evolutionary changes in heap leach technology and regulatory requirements through the past two decades. The first heap pad constructed at the site consisted only of a 12-inch clay layer, side berms, and a simple reclamation plan. With each successive addition or modification there came additional permit stipulations. The operators also voluntarily added more engineered controls. In 1990, the State required the heaps to be neutralized to a cyanide level of 0.22 mg/1 WAD cyanide, and declared that heap slopes greater than 2:1 would no longer be acceptable.

A pilot study of rinsing techniques was begun at the Zortman Landusky heaps in 1982. It was followed with a cyanide degradation study in 1986. These investigations were conducted as part of the detoxification and closure program for the three heaps. The rinsing and degradation studies found that rinsing of the heaps was an effective means of accelerating (compared to natural degradation) cyanide, metal, and nitrate removal. (Schafer and Associates 1991a)

Prior to rinsing of the heaps, the Landusky heaps were allowed to degrade naturally (through natural processes of volatization, oxidation, formation of thiocyanate, and biodegradation). Natural degradation was followed by rinsing of the heap with fresh water to reduce WAD cyanide concentrations in solution. (Schafer and Associates 1991a)

The facility concluded that rinsing with one pore volume removes 50 to 90 percent of cyanide and metals in pore water and was an effective means of accelerating the rate of cyanide and metal degradation in heaps. (Schafer and Associates 1991a)

During the rinsing of the Landusky heaps, however, several issues were raised: the amount of solution retained in the heap, long-term seepage from decommissioned and reclaimed heaps, the long-term degradation of cyanide in heaps, and the attenuation of metals in heaps. During investigations at the site, evidence suggested that movement of water through the heap was rapid and homogenous. (Schafer and Associates 1991a)

Periodically, Landusky land applies neutralized solution to a specified parcel of land at the site. In 1987, during one round of land application four million gallons were applied during a five day period. Cyanide concentration of the water applied to the ground were above 3 mg/1 (exact concentrations were not obtained for this report).

A.2.1 McCoy/Cove Mine, Echo Bay Mining Company, Nevada, INCO process

The McCoy/Cove Mine, near Battle Mountain, Nevada, operates a vat leach operation for extraction of gold. The facility added an INCO cyanide treatment system in 1990 to its operations after experiencing more than 1000 water-fowl deaths caused by migratory birds drinking out of its cyanide tailings impoundment (such deaths are in violation of the U.S. Migratory Bird Treaty Act).

At the McCoy mine, the INCO process is used to remove cyanide from the tailings pulp after gold has been recovered from the milling process. Prior to the use of INCO, the spent tailings were discharged directly to a tailings pond. The liquid fraction of the tailings was reused as make-up in the leaching process. The cyanide-containing liquid in the 145 hectare tailings pond attracted the migratory birds in a desert area with few open bodies of water.

The system treats tailings pulp (thickener) underflow containing 268 kg WAD cyanide/hour in two parallel reactors (40 percent solids; 8,500 stp mill throughput) to reach a target residual cyanide level of 25 mg/1 WAD cyanide (it can reach 5 mg/1 WAD cyanide, if necessary). Other INCO references suggest that the McCoy/Cove effluent has total cyanide levels below 10 mg/1. Periodic WAD cyanide analysis, as well as SO_2 feed, slurry flow rate, pH, and percent solids, are monitored. Tailings are disposed of in a tailings impoundment where WAD cyanide levels are

monitored daily, ranging from 4 to 7 ppm. (Devuyst 1992, INCO 1992) The facility has cut its cyanide consumption by reusing cyanide recovered from the INCO process.

Case Studies

Presented below are selected case studies for mines where acid drainage from mine wastes or mine works has occurred. Both active sites and sites on the National Priorities List are described. The active sites were selected to represent sites where the potential to generate acid was either not considered, or not expected, but later developed. Case histories for the Newmont Rain facility in Nevada, Cyprus Thompson Creek in Idaho, and the LTV Steel Mining Company Dunka site in Minnesota are presented below in Sections 4.1, 4.2, and 4.3, respectively. EPA visited each of these sites to further its understanding of the mining industry. Each site has experienced acid generation problems; however, it is important to note that each is also taking corrective action to mitigate the problem. The companies are working with appropriate State and Federal agencies to determine long-term treatment needs.

The EPA (1991) has prepared National Priorities List (NPL) Site Summary Reports for the mining sites on the NPL. NPL sites were selected from these reports if acid generation was identified as a problem. Using this criteria, seven of 56 mining-related sites were selected for review. The purpose of the review was to determine if acid generation predictive tests were conducted at individual sites, and if such tests were conducted, how the data were used. The review included examination of available literature on each site and interviews with each site=s Remedial Project Manager (RPM). Based on incomplete information for the seven sites studied, tests for either acid prediction or pH prediction have not been conducted at Silver Bow Creek, Eagle Mountain Mine, Tar Creek, and Whitewood Creek. Eagle Mountain Mine and Silver Bow Creek have not conducted prediction tests because acid generation is such a clear and extreme problem (Taylor 1993, Forba 1993, and Overbay 1993).

Sites that have assessed the acid generation potential include Clear Creek/Central City, California Gulch, and Iron Mountain. At Clear Creek acid/base potentials were calculated for waste materials and potential acid generation testing is being required by the City of Clear Creek for any new development that disturbs the ground. Both the RPM and State contact for Iron Mountain indicate that acid generation predictive tests have been done while mucking out tunnels. Acid generation prediction has also occurred at California Gulch. Further details on the sampling and analytical methods used to predict acid generation have not been obtained. Sections 4.4 through 4.7 provide details on acid generation prediction experiences at these three NPL sites (Fliniau 1993, Hyman 1993, and Sugarek 1993).

A.3 NEWMONT RAIN FACILITY, ELKO COUNTY, NV

A.3.1 Introduction

EPA visited Newmont Gold Company=s Rain facility in September of 1991 (U.S. EPA 1992b). The facility is located on approximately 627 acres, 9 miles southeast of Carlin in Elko County, Nevada. The facility is a mining-milling-leaching operation for beneficiating disseminated gold ore. Ore and waste rock are mined from an open pit. Of the ore removed from the mine, over forty percent is milled and beneficiated by the carbon-in-leach method at a current rate of about 840,000 tons per year (TPY). The remaining ore (about 1,000,000 tons per year) is leached using a modified heap method referred to as a valley leach. An average of 35,000 tons of material was being removed from the mine each day as of late 1991. Of this, 5,500 tons was ore grade, 29,500 tons was waste rock. This rate varies between 7,000 and 40,000 tons per day, respectively.

Most of the ore-grade material is taken from the oxidized sediments of the Webb Formation, proximal to the Rain fault. Gold concentrations in this material range from 0.01 to 0.15 ounces of gold per ton of rock. According to Newmont, sulfide-bearing rock does not contain gold in sufficient quantity to be economically recoverable, and is therefore disposed of as waste rock.

A.3.2 Waste Rock

Projected waste rock tonnage was estimated to be 41.4 million tons by the end of 1990, and 62.5 million tons during the life of the mine. In late 1991, the waste rock dump covered 211 acres north and east of the pit. Waste rock production from the pit averaged 29,500 tons per day. Of this, 7,500 tons were sulfidic and 22,000 tons oxide. Newmont had estimated that by mine closure in 1995, there will be more 62.5 million tons of waste rock; of this, 77.8 percent was expected to be most oxidized mixed sedimentary material of the Webb Formation (some of which will contain sulfide mineralization), 15.4 percent carbonaceous and potentially sulfidic, 4.3 percent limestone of the Devil=s Gate Formation, and 2.5 percent alluvium from surface deposits.

Prior to the spring of 1990, sulfide, oxide, and calcareous waste rock were disposed of together. On May 8, 1990, acid drainage was observed flowing from the base of the waste rock dump and into the unnamed drainage above Emigrant Spring, toward Dixie Creek. Inspection of the drainage downstream of the dump revealed that approximately two miles of the channel contained a red-brown precipitate. Discharge to the drainage was estimated by Newmont to be 3 g.p.m. According to Newmont, snow removed from the roads was disposed of on the waste dump. As the snow melted, it infiltrated the waste rock pile, oxidizing sulfur-bearing minerals and generating acid. The solution migrated along pre-mining topography and discharged at the toe of the dump.

Surface-water samples were taken along 5 points in the drainage above and below Emigrant Spring in May, June, and July of 1990. They showed pH values ranging from 2.37 to 3.21 near the base of the waste rock at the discharge point, and from 6.5 to 8.64 about 4,000 feet downstream. Arsenic levels near the effluent point were 46 ppm in May and 1.5 ppm in July; at the distant sampling point, arsenic levels were 0.023 ppm in May and 0.005 ppm in July. Mercury levels near the discharge point were 0.19 ppm in May and 0.0019 ppm in July; at the distant sampling point, mercury levels were <0.0001 ppm in May and 0.0003 ppm in July.

A.3.3 Acid Generation Prediction

Following detection of the acid generation in 1991, Newmont=s Rain facility Water Pollution Control Permit was revised. As part of the revised permit, Newmont is required to report quarterly on results of Meteoric Water Mobility testing and Waste Rock Analysis. The meteoric water mobility test is an extraction procedure that determines moisture content of the waste, percent of a sample passing -200 mesh, pH of deionized water, and final pH of extract (following 24-hour extraction time). Following the meteoric water mobility test, total carbon, organic-carbon, and sulfur assays are obtained on the composite waste sample by combustion-infrared analysis to measure sulfur and sulfide contents, and to estimate carbonate content. Acid neutralization potential is then measured using titration. The extracted solution is analyzed for nitrate, phosphorous, chloride, fluoride, total dissolved solids, alkalinity, sulfate, and metals. Waste rock analysis is intended to determine the net acid generation potential of the material placed in the waste rock dump during the quarter.

Data for the third and fourth quarters of 1990 and the first quarter of 1991 were examined by EPA following the site visit (U.S. EPA 1992b). Third quarter results for the waste rock analysis indicated a net acid generation potential of -10.6 tons of $CaCO_3$ for each 1,000 tons of waste. This suggests that the wastes generated during this quarter had sufficient buffering capacity to neutralize any acid solution generated by sulfidic material. Fourth quarter results showed a large shift, with an acid generating potential 5.35 tons of $CaCO_3$ for each 1,000 tons of waste. The total acid generating potential of waste rock disposed during this quarter was equivalent to the amount of acid neutralized by 5.35 tons of $CaCO_3$ for each 1,000 tons of waste. For the first quarter of 1991, waste rock analysis data showed a net acid generating potential of 8.57 tons. In these circumstances, Newmont is required to perform kinetic testing according to State of Nevada protocol. Results of this analysis were not available; however, in the third Quarterly Monitoring report for 1991, Newmont indicated that column studies were underway to fulfill this requirement.

A.3.4 Treatment

In response to the drainage, Newmont took the following actions. By May 9 (one day after the drainage was noted), a small pond was constructed to collect the flow from the dump. On May 11, an HDPE liner was installed in the pond, and on May 18, Newmont constructed a cutoff trench across the channel downstream of the collection pond to collect subsurface solution. The trench was twenty feet deep and forty feet across and included an HDPE liner. Inflow to this trench was pumped to the collection pond then trucked to the tailings impoundment for disposal.

The State and BLM approved Newmont=s long-term mitigation plan with construction beginning in November of 1990, and completed in March of 1991. The solution collection and return system consists of surface and subsurface water collection and recovery system. Surface water is collected in a ditch and drains to a sump located at the toe of the waste rock pile. Drainage collected in the sump drains by gravity to a 200,000-gallon capacity, double-lined pond. Subsurface flow is recovered in an HDPE-lined trench and also drains to the double-lined pond. Flows average 23.8 g.p.m. with a maximum of 183 g.p.m.. In the event of a power failure, the pond has a capacity to retain in excess of 65 hours of inflow at the maximum projected flow rate. In addition, storm water from the surface of the waste rock dump and surrounding area is collected in a single-lined, 600,000-gallon pond located just below the double-lined pond. Solution from both ponds is pumped to the mill area and added to the tailings pipeline.

As a long-term mitigation/prevention measure, Newmont began encapsulating sulfidic waste rock within oxidized and/or calcareous waste rock that has either no new acid generating potential or some acid neutralizing potential. As of late 1991, this was being accomplished by placing a pervious layer of coarse oxidized waste rock on the native soil. On this, five feet of compacted oxidized ore was placed. Additional oxide ore was placed against the natural hillslope to act as a barrier. These layers were to act as barriers to water movement into and out of the sulfidic waste pile. In addition, haul trucks follow random routes during construction to compact the material, thereby reducing its permeability. Eventually, the front edge and top will be covered with 15 feet of oxidized material to complete the encapsulation. Prior to encapsulation, sulfide waste rock will be mixed with oxidized material or the limited quantity of calcarious material available to buffer any acidic solution generated. The sulfidic materials are fine to coarse grain sedimentary rocks extracted primarily from the Webb Formation.

Neither the draft nor the final Environmental Assessment prepared for the Rain facility discussed the potential for sulfidic material to generate acid drainage.

A.4 CYPRUS THOMPSON CREEK, CHALLIS, ID

A.4.1 Introduction

EPA conducted a site visit of the Cyprus Minerals Corporation Thompson Creek (Cyprus) facility in September 1991 (U.S. EPA 1992c). Cyprus mines molybdenite (molybdenum disulfide, MoS_2) from an open pit mine near Challis in central Idaho. Cyprus staked its first mineral claims at Thompson Creek in 1967. In 1981, mining operations beagn and the first concentrates were produced in 1983. In late 1991, the Cyprus Thompson Creek Mine site consisted of (1) an open pit mine and two waste rock dumps; (2) a primary in-pit crusher; (3) a mill with grinding and flotation; and (4) a tailings impoundment.

Cyprus has been conducting a study to investigate the potential for the waste dumps and the tailings impoundment to generate AMD. The results of the AMD study of the waste rock and tailings were to be provided to the U.S. Forest Service (USFS) by March 1, 1992. Proposed revisions=s to the facility=s reclamation plan were also to be submitted to the USFS. According to USFS personnel, the revisions to the Plan of Operations were to be subjected to the environmental review requirements of National Environmental Policy Act (NEPA). This review may include preparation of a supplemental Environmental Impact Statement (U.S. EPA 1992c). The AMD study has been requested.

A.4.2 Waste Rock

When mining began in 1981, approximately 130 million tons of overburden were initially removed as Apre-production stripping≅. Most of the overburden was placed in two waste rock dumps (the Buckskin and Pat Hughes dumps) located adjacent to the pit. In 1990, approximately 16.2 million cubic yards of waste rock were generated, consisting mainly of metasediment, quartz monzonite, challis volcanics, and clayey rock (i.e., decomposed volcanics).

A.4.3 Acid Generation Prediction

Both intrusive and metasedimentary rocks have high sulfur content (up to 1.13 and 1.66 percent, respectively). Therefore, in 1990, Cyprus began a study of the potential for AMD generation from the waste rock and tailings, using both static and kinetic test methods. As of late 1991, static testing had been preformed on twenty intrusive rock samples, and 58 metasedimentary rock samples collected from both the lower and upper benches of the pit. For each sample, Cyprus calculated the neutralization potential (NP) and the acid generation potential (AP) to determine the net neutralization potential (NNP) and the NP/AP ratio. The NNP represents the neutralization potential (the tons of calcium carbonate required to neutralize 1,000 tons of waste rock) minus acid generation potential (calculated based on the total sulfur content). According to Cyprus personnel, waste rock with an NP/AP ration in excess of 3:1 was considered non-acid generating. According to USFS personnel, an NP/AP ratio of at least 5:1 should be required before a material is determined to be non-acid forming (U.S. EPA 1992c).

Static testing of eight intrusive rock samples from the lower benches of the pit, close to the ore zone, yielded an average net neutralization potential (NNP), and neutralization ratio (NP/AP) of 0.53 and 1.88:1, respectively. These results exhibited more AMD potential than the average NNP (4.93) and average NP/AP (3.80:1) values obtained from 12 intrusive rock samples from the upper bench. They indicate a greater potential for AMD with intrusive waste rock in the vicinity of the ore zone. The AMD potential decreased with distance from the ore zone. The difference between intrusive rock samples and collected from the upper and lower benches was believed to be caused by a relatively predictable pattern of mineralization and alteration zoning around the ore body.

According to Cyprus, the metasedimentary rocks did not appear to be source of AMD. Cyprus has preformed static testing on the metasedimentary rock in the lower benches and found NNP and NP/AP values of 24.95 and 3.11:1, respectively. It should be noted that, while the metasedimentary rocks are considered non-acid forming by Cyprus (NP/AP greater than 3:1), the average NP/AP ratio is less than the minimum (5:1) suggested by the USFS. Metasedimentary rock samples obtained from the upper benches showed average NNP and NP/AP values of 19.02 and 8.52:1, respectively. Though the average NNP value did not increase in samples from the upper bench, the NP/AP ratio increased significantly, supporting the theory that AMD potential decreases with distance from the ore zone.

Kinetic testing of intrusive and metasedimentary rock was ongoing in 1991 for those static test samples showing acid generation potential. Results of these tests were to be incorporated into the AMD study as soon as they became available.

A.4.4 Tailings

During the ongoing acid drainage study, indications of acid generation were found in the tailings. As of late 1991, the tailings impoundment covered a total of approximately 150 acres with the embankment covering 60-70 acres and the tailings pond behind the embankment approximately 90 acres. According to Cyprus personnel, tailings oxidation to a depth of several feet has been evident for over two years (U.S. EPA 1992c).

A.4.5 Acid Generation Prediction

In October 1990, ten hollow stem auger borings were completed in the tailings embankment. Samples collected from these borings were subjected to humidity cell testing, and showed that the average sulfur content of the tailings sands was 0.79 percent and the pH ranged from 3.5 to 7.3 s.u. (Analyses of tailings sands have shown pH levels as low as 3.0) In addition, of eight samples tested, six produced elevated iron and sulfate concentrations, and associated increased acidity, within a 15-week test period. The kinetic tests affirm the reactive nature of the tailings found in the static test results.

According to Cyprus personnel, the tailings pond and the seepage return pond were not a problem (pH > 5.7 s.u.). However, in 1991, Cyprus conducted a water quality trend analysis for six surface water quality monitoring locations in the tailings impoundment area, These locations included the main drain of the rock toe, springs located on the left and right abutments of the rock toe, the discharge from the rock toe, the sump below the seepage return pond dam, and Bruno Creek (immediately downstream of the sump). This analysis found that during the period 1981-1990, (1) pH decreased at four locations (but not at the left and right abutment springs), (2) sulfate had increased at all locations, (3) iron had increased at four locations, not at the left and right abutment springs), and (4) no trends in zinc, copper, or arsenic were recognized. The increase in sulfate concentrations was attributed to tailings oxidation and acid generation.

A.4.6 Treatment

Cyprus applied trisodium phosphate (TSP) to tailings embankment sand to address the AMD problem. Previous column testing had found that TSP addition increased the pH, and reduced iron concentrations in leachate samples. According to Cyprus=s consultant, two TSP tests, humidity cell tests and large scale tests, were being conducted in 1991 to determine TSP=s effectiveness in controlling AMD from the embankment, and maintaining impoundment water quality. However, because the tailings impoundment unit has no discharge and water from the impoundment, seepage return pond, and pump back system is returned to the mill, the TSP application was expected to cause elevated phosphorous levels in the reclaim water. Cyprus personnel indicated these levels may adversely affect flotation operations and that this issue was being studied.

Cyprus=s original plan for reclamation of the tailings impoundment indicates that Cyprus initially anticipated that water quality standards could be met by diluting impoundment seepage with natural runoff. No water treatment beyond sediment control was expected to be required. However, the original reclamation plan did not consider the AMD issue. According to Cyprus personnel, the AMD problem could extend well beyond the life of the mine and perpetual care /treatment may be necessary. Therefore, Cyprus was evaluating remedial alternatives (other than perpetual care) and was preparing to submit a revised tailings pond reclamation plan (as a modification to their operating plan).

Alternatives to be considered included installing an additional flotation unit to remove pyrite and/or in-place treatment of tailings with trisodium phosphate as a buffer. Preliminary flotation tests have been conducted to investigate the possibility of removing sulfides from the tailings prior to disposal in the impoundment. Test results indicated that a high percentage of pyrite may be recovered. Limited static testing performed on a whole tailings sample from which pyrite was recovered indicated a NP/AP ratio in excess of 4:1 compared to an average value of 0.84:1 for all tailings analysis.

According to Cyprus personnel, oxidation had only been found to occur in the top two to three feet of tailings (despite the results of analyses of the 1990 borehole samples that showed oxidation at all depths down to 150 feet). Therefore, an additional alternative under consideration was to encapsulate the tailings. Information on specific types of cover materials was not provided. Additionally, Cyprus was investigating the potential use of wetlands treatment.

A.5 LTV STEEL MINING COMPANY, THE DUNKA SITE, MINNESOTA

A.5.1 Introduction

EPA visited the LTV=s Dunka site in August 1991 (U.S. EPA 1992c). This site is located approximately 20 miles northeast of LTV Steel Mining Company=s (LTV SMCo.) Hoyt Lakes facility. This site is on private, State, Bureau of Land Management, and U.S. Forest Service lands; LTV SMCo. holds surface and mineral leases for the area. The Dunka pit is part of the eastern-most extension of the Biwabik iron formation and is one of the smaller pits on the Mesabi range at three miles in length. Although additional material may be removed from the pit for beneficiation, in 1991, plans called for no further exploration activity at the site or enlargement of the pit.

A.5.2 The Acid-Generating Duluth Complex

The taconite ore at the Dunka Site contacts Duluth Complex material (DCM), which must be removed to reach portions of the taconite ore deposit. The Duluth Complex is a sulfur-containing, mafic intrusive rock unit, considered to be one of the largest known sources of copper and nickel resources. As of late 1991, LTV SMCo. had removed and placed in Agabbro≅ stockpiles approximately 50 million tons of Duluth Complex material containing an average of more than 0.2 mass percent copper oxides and/or 0.05 mass percent nickel oxides as gabbro stockpiles.

The remaining Duluth Complex material stockpiles were categorized as waste rock stockpiles and are made up of material containing less than 0.2 percent copper oxide and less than 0.05 percent nickel. Since these waste rock stockpiles were constructed in 1976, monitoring of drainage from the piles has revealed a decrease in pH levels, as well as an increase in trace metal concentrations. Copper and nickel concentrations as high as 1.7 and 40 mg/L, respectively, were observed in seepage/runoff from Duluth Complex waste rock stockpiles at the site. In addition, during sampling conducted by the Minnesota Department of Natural Resources between 1976 and 1980, pH values as low as 5.0 at Seep 1 were reported.

A.5.3 Acid Rock Drainage Methods

To address this drainage, the Minnesota Department of Natural Resources, in conjunction with LTV SMCo., constructed full scale test piles of the Duluth Complex material to monitor its acid generation potential. The MDNR continues to monitor the test piles and study acid generation. Lapakko (1988) conducted kinetic tests of Duluth Complex material using a humidity cell. Nine samples were selected from core material and one sample from a test stockpile. This experimental method was selected based on ongoing field test results, which demonstrated a strong correlation between sulfur content, trace metal mobility, and acid production. Laboratory scale tests provided better control and simplified analysis. Sulfur content was identified as the independent variable. Samples that had variable sulfur content were selected. Part of the study was to determine the feasibility of extrapolating laboratory tests to operational conditions.

Each cell was loaded with 75 gram rock samples passing 100 mesh but less than 270 mesh. Samples were rinsed with 200 ml of distilled-deionized water, which was allowed to remain in contact with the sample for five minutes. Rinse water was collected and filtered through a 45 micron filter. At the beginning of the experiment, the samples were rinsed five times to remove oxidization products generated during sample preparation. Two rinses were used each week during the remainder of the experiment. Between the weekly rinsings, the samples were stored in a box fitted with temperature and humidity controls.

The laboratory study found that drainage pH decreased as the sulfur content of the sample increased. Drainage pH also decreased as the experiment time increased. Both of these findings are consistent with field observations on pH variation correlated with sulfur content and time. Based on the data, Lapakko (1988) concluded that the small particles (<2.0 mm) have a large influence on field stockpile drainage equity. The weighted average sulfur content for particles in this fraction is 1 percent compared to 0.6 percent in the bulk rock. Most of the sulfur occurs as pyrrhotite. The higher sulfur content combined with the higher surface area of these particles make this fraction susceptible to more intense oxidation reactions.

A.5.4 Environmental Risks

Toxicity testing of the leachate showed that copper and nickel concentrations exceeded the 48-hour lethal concentration (LC50) for *Daphnia pulicaria*; nickel concentrations also exceeded the 96-hour LC50 for fathead minnow. Concentrations of calcium, magnesium, and sulfate in the stockpile drainage were also elevated. According to LTV SMCo., there was some question whether the metals were the toxic agent.

Most of the seepage from waste rock piles at the Dunka site has historically been discharged to Unnamed Creek. Unnamed Creek flows into Bob Bay, a part of Birch lake. In a 1976-77 study of trace metals in Bob Bay, it was found that concentrations of copper, nickel, cobalt, and zinc in

the waters of the Bay were higher than the regional average concentrations and decreased with distance from the mouth of Unnamed Creek. Elevated metal concentrations were also observed in the sediments, as well as in aquatic plant and clam tissue. In the study, it was estimated that the total discharge from the Dunka watershed into Bob Bay through Unnamed Creek was 500 million gallons per year. Unnamed Creek contributes more than 90 percent of the trace metals load to Bob Bay. Annual loading is over one ton of nickel. Less than 40 percent of this nickel load was found to be removed from the system through natural lake processes. According to LTV SMCo., carbon dating of sediment samples from Bob Bay indicates significant metal concentrations which predate mining.

A.5.5 Treatment

As of late 1991, the State and LTV SMCo. were working to develop technologies to mitigate leachate generation and release of trace metals associated with stockpile drainage. The technologies being tested and employed included pile capping/channeling to limit infiltration, active treatment in a neutralization pond to lower pH and remove metals, and use of artificial wetlands to remove metals. The ultimate goal was a passive treatment system that would require little or no maintenance (U.S. EPA 1992d).

A.6 CALIFORNIA GULCH

The California Gulch NPL site is located in the upper Arkansas River in Lake County, Colorado. It is bounded by the Arkansas River to the west and the Mosquito Mountains to the east, and is approximately 100 miles southwest of Denver. The study area for the remedial action encompasses approximately 15 square miles, and includes California Gulch and the City of Leadville. California Gulch is a tributary of the Arkansas River. Mining for lead, zinc, and gold has occurred in the area since the late 1800's. The site was added to the NPL in 1983. (U.S. EPA 1991).

A Remedial Investigation conducted by EPA in 1984 indicated that the area is contaminated with metals (including cadmium, copper, lead, and zinc migrating from numerous abandoned and active mining operations). A primary source of the metals contamination in the Arkansas River is acid-mine drainage from the Yak Tunnel into California Gulch. The acid dissolves and mobilizes cadmium, copper, iron, lead, manganese, zinc, and other metals. The tunnel and its laterals and drifts collect this metal-laden acidic water, and drain it to the tunnel portal. The tunnel drains into California Gulch and then to the Arkansas River. The Yak Tunnel=s discharge contributes to the contamination of the California Gulch, the Arkansas River, and the associated shallow alluvial ground-water and sediment systems. From previous investigations and sampling data, it was concluded that, as of the early 1980's, the Yak Tunnel discharged a combined total of 210 tons

per year of cadmium, lead, copper, manganese, iron, and zinc into California Gulch, which is biologically sterile (U.S. EPA 1991). Results of acid generation predictive tests of tailings and waste rock samples were not available for this report.

A.7 CLEAR CREEK/CENTRAL CITY

The Clear Creek/Central City NPL site is located approximately 30 miles west of Denver, Colorado, and includes the Clear Creek mainstream and the North and West forks of Clear Creek. Active operations, which began in 1859, include gold, copper, lead, molybdenum, and zinc mining. Initial investigations at the site focused on the discharges of Acid Mine Drainage (AMD) and milling and mining wastes from five mines/tunnels in the Clear Creek and North Clear Creek Drainages. The five mines/tunnels of interest are: (1) the Argo Tunnel; (2) the Big Five; (3) the National Tunnel; (4) the Gregory Incline; and (5) the Quartz Hill Tunnel. The first two are portals along Clear Creek and the last three are in the North Clear Creek Drainage. They are close to the cities of Idaho Springs, Blackhawk, and Central City. Associated with AMD is contamination of surface drainages by metals in solution such as cadmium, chromium (VI), lead, manganese, nickel, and silver (U.S. EPA 1991).

Acid/base potentials, similar to acid/base accounting, of waste materials were tested as part of the Remedial Investigation. The acid/base potentials (NNP) were calculated as the neutralization potential (NP) minus the potential acidity (AP). Results indicated that waste materials at the Gregory Incline, the Quartz Hill Tunnel, and the Argo Tunnel have the capacity to generate large quantities of acid leachate. The mill tailings at the Gregory Incline are especially capable of producing acid through the oxidation of large quantities of pyrite. For example, the average acid potential for the Gregory Incline mill tailings was -21.5, the waste rock was 1.7, and the alluvium was 11.6 (a negative acid/base potential indicates acid forming potential). In the waste rock and alluvium, 11 of 18 and 2 of 13 samples showed acid forming potential. Information on the types of sampling and analytical methods used was not available.

The City of Blackhawk, with guidance from EPA, is requiring, through a city ordinance, acid generation potential testing of onsite materials prior to any development activities. Central City is in the process of doing the same. The ordinance requires that, for any excavation or site development, a sample collection plan that includes chemical analysis of acid/base potential must be prepared. The ordinance requires that the tests conform to the methods outlines in EPA-670/2-74-070, *Mine Spoil Potential for Soil and Water Quality* or an equivalent method, and that sampling must be representative of the conditions at the property. If the acid/base potential is negative, the applicant must have a mitigation plan approved by the city (Fliniau, 1993).

A.8 IRON MOUNTAIN MINE

The Iron Mountain Mine is a 4,400-acre NPL site in Shasta County, California, approximately nine miles northwest of the City of Redding. Between 1865 and 1963, the area was used for the mining and processing of copper, silver, gold, zinc, and pyrite. In 1983, Iron Mountain Mine was added to the NPL. Acid mine drainage, leaching from both the underground mine workings and from the tailings piles locate at the site, is causing zinc, cadmium, and copper contamination of the Spring Creek Watershed and the Sacramento River. Environmental damage is primarily in the Sacramento River and tributaries in the Spring Creek and Flat Creek watersheds, where fishery productivity loss and periodic fish kills have been observed. Drinking water drawn from the Sacramento River for the City of Redding (population 50,000) is also threatened (U.S. EPA 1991).

In general, acid mine drainage generation is seasonal and is accelerated during periods of heavy rainfall. According to the EPA, the annual average rate of acid mine drainage at the site is 100 gallons per minute (g.p.m.) with peak flows of 300 to 600 g.p.m.. The average loading per day to the Spring Creek Watershed from Iron Mountain Mine is 423 lbs of copper, 1,466 lbs of zinc, and 10.4 lbs of cadmium. (U.S. EPA 1991, Biggs 1991).

According to the Remedial Project Manager, acid generation potential tests were conducted while the tunnels were being mucked out. The procedures used are those required by California State law. Information on test results and sampling and analytical methods used was not available (Hyman 1993, Sugarek 1993).

A.9 SILVER BOW CREEK/BUTTE AREA SITE

The Silver Bow Creek/ Butte Area NPL site is one of four separate but contiguous Superfund Sites located along the course of the Clark Fork River in southwestern Montana. The Silver Bow Creek/Butte Area Superfund Site is the largest (450 acres) and most complex of the four sites. The site was listed on the NPL in 1983. The Silver Bow Creek/ Butte Area site includes the Cities of Butte and Walkerville (population 38,000), the Berkeley Pit (a non-operating open-pit copper mine); numerous underground mine workings; the Continental Pit (operated by Montana Resources); Silver Bow Creek; Warm Springs Ponds (mine tailings); and Rocker Timber Framing and Treating Plant.

In the early 1980s the Berkeley Pit open pit mine was closed and dewatering pumps were shut down. As a result, the interconnected underground workings and the open pit began filling with water. EPA is concerned with the waters filling Berkeley Pit because they are highly acidic (the RI shows pH values ranging between 2.5 and 3.3, depending upon at what depth the samples were taken) and contain high concentrations of copper, iron, manganese, lead, arsenic, cadmium,

zinc, and sulfates. If the water continues to rise in the Berkeley Pit, contaminated water may eventually flow into shallow ground water (alluvial aquifer) and into Silver Bow Creek, creating the potential for significant environmental impacts and human health problems (U.S. EPA 1991). There have been no tests performed to predict pH changes either in Berkeley Pit or the drainages that feed Berkeley Pit (Forba 1993). Total acidity has been tested for some samples collected at the Silver Bow Creek site. Information on the materials sampled, analytical methods, and results were not available.

AMPCO Metal Manufacturing Company, Inc.

Various pollution prevention case histories have been documented for nonferrous metals refining industries. In particular, the actions of the AMPCO Metal Manufacturing Company, Inc. typify industry efforts to simultaneously lessen the impact of the industrial process on the environment, reduce energy consumption, and lower production costs.

AMPCO Metal Manufacturing Company, Inc., in Ohio is participating in the development of pollution prevention technologies. The project, sponsored by the U.S. DOE and EPA, consists of researching and developing the use of electric induction to replace fossil fuel combustion currently used to heat tundishes. Tundishes are used to contain the heated reservoir of molten alloy in the barstock casting process. The fossil fuel combustion process currently used requires huge amounts of energy and produces tremendous amounts of waste gases, including combustion bases and lead and nickel emissions. According to new OSHA regulations, lead emissions from foundries must be reduced by 80 percent by 1998.

Heating the tundish by electric induction instead of fossil fuel combustion will substantially improve the current process, saving energy and reducing pollution. Energy efficiency will jump to an estimated 98 percent, saving 28.9 billion Btu/yr/unit. Industry-wide energy savings in 2010 are estimated to be 206 billion Btu/yr, assuming a 70 percent adoption at U.S. foundries.

In addition to the energy savings, the new process also has substantial environmental benefits. Along with the elimination of lead and nickel gases, carbon dioxide, carbon monoxide, and nitrogen oxide emissions from combustion will decrease. The consumption of refractory (a heat-resisting ceramic material) will decline by 80 percent, resulting in a similar reduction of refractory waste disposal. In all, prevention of various forms of pollution is estimated to be 147 million lb (66.7 million kg)/yr by 2010.

Economically, the elimination of lead and nickel emissions will result in an improved product because exposure of the metal to combustion gases in the current process results in porosity and entrainment of hydrogen gas in the metal. Overall, AMPCO estimates an annual savings in operations and maintenance expenses of $1.2 million with the use of this technology. Assuming the same 70 percent industry adoption, economic savings by 2010 could reach $5.8 million.

Without the new electric induction heating process, the capital costs required for compliance could be $3 million.

APPENDIX B
LIST OF VENDORS

ENVIRONMENTAL EQUIPMENT AND SUPPLIES

Denver Mineral Engineers, Inc.
P.O.Box 3556
Littleton, Colorado 80161
Tel: (303) 932-6280
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E-mail: sales@denvermineral.com

ASOMA Instruments, Inc.
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Austin, Texas 78759
Tel: (512) 258-6608
Fax: (512) 331-9123
Toll Free: (800) 580-6608
E-mail: sales@asoma.com

Environmental Liners, Inc.
2009 N. Industrial Road
Cortez, Colorado 81321
Tel: (800) 821-0531, ext. 114
Fax: (970)565-8844
E-mail: eliners@environmental-liners.co

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Fax: (801) 295-2346
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INPROSYS
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Salem-republic
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Environmental Software

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BIBLIOGRAPHY

Arizona Department of Environmental Quality. 1996. *Arizona Mining Heavy Equipment and Fleet Maintenance: Pollution Prevention Practices and Opportunities*. Pollution Prevention Unit, June.

Block, M.R. 1997. *Implementing ISO 14001*. Milwaukee: ASQC Quality Press.

Bray, John L. 1947. *Non-ferrous Production Metallurgy*. Second ed. New York: John Wiley and Sons.

Butts, Allison. 1971. *Metallurgical Problems*. Second ed. New York and London: McGraw-Hill.

Cascio, J., G. Woodside, P. and Mitchell. 1996. *ISO 14000 Guide: The New International Environmental Management Standards.* New York and London: McGraw-Hill.

Davey, T.R.A. 1979. *Advances in Lead, Zinc, and Tin Technology - Projections for the 1980's. Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control*, John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 48-65.

Davey, T.R.A. 1969. ASmelting of Low Grade Tin Concentrates,≅ *Australian Mining*, August 1969, pp. 62-65.

Davey, T.R.A. and J.M. Floyd. 1966. ASlag-Metal Equilibria in Tin Smelting,≅ *Proc. Australasian Institute of Mining and Metallurgy*, No. 219, Sept. 1966, pp. 1-10; and discussion and contributions in *Proc. Australasian Institute of Mining and Metallurgy*, No. 223, Sept. 1967, pp. 75-80.

Deming, Dale, Magma Copper Company. 1992. APollution Prevention in the Mining Industry.≅ Presented at Southern Arizona Pollution Prevention Conference: Regulations, Application, and Policy.

Dyer, Jon, and Nicholas Mignone. 1983. *Handbook of Industrial Residues*. Park Ridge, NJ: Noyes Publications.

Floyd, John M. 1979. AThe Physical Chemistry of Tin Smelting. A*Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control.* John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 508-531.

Foo, K.A. and Floyd, J.M. 1979. ADevelopment of the Matte Fuming Process for Tin Recovery from Sulphide Minerals. A *Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control*, John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 786-800.

Front Range Community College Hazardous Materials Program. 1993. *Pollution Prevention and Waste Minimization Opportunities for the Mining Industry.* Prepared for US EPA.

Harris, John H. 1979. AThe Problems of Tin.≅ *Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control*, John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 733-753.

Idaho Department of Lands. 1992. *Best Management Practices for Mining in Idaho.* Prepared in conjunction with other state and federal agencies through the Idaho Mining Advisory Committee. Boise.

ISO 14001: Environmental Management Systems X Specification with Guidance for Use. 1996. ASQC.

Knoerr, Alvin W., ed. 1980. *Mineral Facts and Problems.* Washington, DC: U.S. Bureau of Mines, US Government Printing Office.

Lyle, E.S. Jr. 1987. *Surface Mine Reclamation Manual.* New York: Elsevier Science Publishing Co.

Newton, Joseph. 1959. *Extractive Metallurgy*. New York: John Wiley and Sons.

Noyes, Robert. 1993. *Pollution Prevention Technology Handbook.* Park Ridge, NJ: Noyes Publications, 1993.

Oberbeckmann, Friedrich Karl, and Porten, Manfred. 1979. ATin Smelting at Berzelius, Duisberg (Germany). A *Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control.* John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 771-785.

Pearce, S.C. 1979. ADevelopments in the Smelting and Refining of Tin.≅ *Lead-Zinc-Tin >80, Proceedings of a World Symposium on Metallurgy and Environmental Control*. John M. Cigan, Thomas S. Mackey, and Thomas J. O=Keefe, eds. New York: American Institute of Mining, Metallurgical Engineers, pp. 754-770.

Rosenquist, Terkel. 1974. *Principles of Extractive Metallurgy.* New York: McGraw-Hill, pp. 296, 397-398.

United Nations Environment Program. *Environmental Aspects of Selected Non-ferrous Metals Ore Mining.* UNEP Technical Report, Series No. 5. New York.

U.S. Department of Commerce, 1996. *Mining Industry Equipment: Chile. Industry Sector Analysis*. Washington, DC.

U.S. Department of Commerce, 1995. *Mining Equipment: Peru. Industry Sector Analysis*. Washington, DC.

U.S. Department of Commerce, 1997a. *Mining Equipment: Venezuela. Industry Sector Analysis*. Washington, DC.

U.S. Department of Commerce, 1997b. *Mining Trends: Peru. International Market Insight.* Washington, DC.

U.S. Department of Health and Human Services. 1985. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.* Prepared by Public Health Service, Centers for Disease Control, and National Institute for Occupational Safety and Health. October. Washington, DC.

U.S. Department of the Interior, Bureau of Land Management. *Solid Minerals Reclamation Handbook*. BLM Manual Handbook H-3042-1. Washington, DC.

U.S. Environmental Protection Agency, 1973. *Processes, Procedures, and Methods to Control Pollution from Mining Activities*. EPA-430/9-73-011. October. Washington, DC.

U.S. Environmental Protection Agency. 1995a. *Profile of the Mining Industry.* EPA Sector Notebook 310-R-95-008. Washington, DC. September.

U.S. Environmental Protection Agency. 1995b. *Profile of the Nonferrous Metals Industry*. EPA 310-R-95-010. Washington, DC.

Washington State Department of Natural Resources. 1996. *Best Management Practices for Reclaiming Surface Mines in Washington and Oregon.* Prepared in cooperation with the

Washington Division of Geology and Earth Resources and the Oregon Department of Geology and Mineral Industries. Open-File Report 96-2. Olympia.

Williams, Roy E. 1975. *Waste Production and Disposal in Mining, Milling, and Metallurgical Industries.* Miller Freeman Publications.

Witkowsky, D.S. 1995. *Pollution Prevention in Mining and Mineral Processing: Waste Assessments for Mines and Mills*. Washington, DC: U.S. Department. of the Interior, U.S. Bureau of Mines.

World Bank. 1996. *A Mining Strategy for Latin America and the Caribbean.* World Bank Technical Paper No. 345. Washington, DC.

Wright, P.A. 1982. *Extractive Metallurgy of Tin*, second ed., Amsterdam: Elsevier.

Acknowledgements

This manual was prepared under the sponsorship of the United States Agency for International Development, Latin America and Caribbean Bureau (USAID/LAC) by Hagler Bailly, Inc., principal contractor of the Environmental Pollution Prevention Project (EP3).

The technical research was done by Miguel Franco of Hagler Bailly and Jan Muller-Vollmer, EP3 consultant, under the direction of Lino Gallo of Hagler Bailly.

EP3 thanks Dr. Gilbert Jackson of USAID/LAC for his valuable comments and support, Mr. James Sturgess for the first technical review of the manual and Mr. William Hirt for the first and final reviews of the manual.

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